Conceptual design of dry bulk terminals

by

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Declaration

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March 2021

Abstract

The global economy continues to be fuelled by the burning of coal in power stations and the erection of infrastructure using steel made from iron ore. New dry bulk terminal projects, or the upgrade and refurbishment of existing dry bulk terminals, may thus need to be considered in order to meet increased demand of these commodities. Dry bulk terminals are primarily used for the movement of dry bulk commodities which may be categorized into two categories, viz:

- major bulks which include iron ore, coal, grains, bauxite/alumina and rock phosphates; and
- minor bulks which include sugars, cements and fertilizers;

A dry bulk terminal project may span over several years and comprise of multiple stages, each requiring a considerable amount of capital investment and as such, project developers may be required to assess several options prior to proceeding with detailed design. The present study includes the use of some current design methods for the development of a new conceptual design tool which is able to rapidly generate a range of key output parameters that may be considered during project feasibility stages. The new conceptual design tool is generic enough to cater for a range of throughputs, shiploader configurations, stockyard machinery configurations and landside equipment configurations and provides a range of outputs for each major infrastructure element of a dry bulk terminal. The new conceptual design tool provides a range of options (termed as Concept Options) and considers a number of inputs including varied vessel sizes and varied annual throughput capacities. Key output options are then produced in terms of the number of berths, the quantities and capacities of terminal handling equipment, the configuration of the stockyard area and size of area required for commodity storage.

Given the generic and flexible nature of the new conceptual design tool, it has been developed by the Author in Microsoft Excel and has been developed to cater for the provision of a range of parameters that may be considered during the conceptual design of single-product export and import dry bulk terminals. The new conceptual design tool is modular in form, with each of its three modules accounting for one major element of a dry bulk terminal, viz:

- Module 1 – Seaside handling and configuration;
- Module 2 - Landside handling and configuration; and
- Module 3 – Stockyard handling and configuration

Several test cases were undertaken with a total of 7 terminals selected for comparative analysis (6 operational and one conceptual). It is not the aim of the new conceptual design tool to provide a single or deterministic output but to provide a range of output options that project developer(s) may consider, before selecting their desired output. Given the specificities of a particular project, it was found that in general, the new conceptual design tool generated, on average, circa 240 Concept Options and Sub-Concept Options for each major element of a terminal. These Concept Options included the operational dry bulk terminal layouts, as well as provided additional options for consideration. In addition, the Concept Options generated by the new conceptual design tool may be considered by project developer(s) and user(s) as a range of (feasible) options for further evaluation during subsequent (detailed) design phases.

The new conceptual design tool is capable of generating a large number of Concept Options for a variety of inputs and is only restricted by the input limitations defined by the user. However, the new conceptual design tool may be expanded through future studies in respect of the incorporation of its ability to accommodate calculations for more than one commodity at a time, the incorporation of stockyard lanes with differential lengths and/or widths or the incorporation of the initial capex requirements for each infrastructure element in order to enable a cost-driven conceptual design optimisation process.

Opsomming

Die wêreldekonomie word steeds aangedryf deur die verbranding van steenkool in kragstasies en die oprigting van infrastruktuur met behulp van staal wat van ystererts gemaak word. Nuwe projekte van droë grootmaateindpunte of die opgradering en opknapping van bestaande droë grootmaateindpunte moet dus oorweeg kan word om aan die verhoogde vraag na hierdie goedere te voldoen. Droë grootmaateindpunte word hoofsaaklik gebruik vir die vervoer van droë grootmaatgoedere wat in twee kategorieë ingedeel kan word, naamlik:

- Meerdere grootmaatgoedere wat ystererts, steenkool, graan, bauxiet / alumina en rotsfosfate insluit; en
- Mindere grootmaatgoedere soos suiker, sement en kunsmis.

'n Projek van 'n droë grootmaateindpunt kan oor 'n aantal jare strek en bestaan uit veelvoudige fases, wat elk aansienlike kapitaalbelegging benodig. As sodanig, behoort projekontwikkelaars verskeie opsies te beoordeel voordat hulle met die daaropvolgende detailontwerpfase voortgaan.

Die huidige studie sluit die gebruik van die huidige ontwerpmetodes vir die grootte van droë grootmaateindpunte in, sowel as die ontwikkeling van 'n konseptuele ontwerpinstrument wat konseptuele veranderlikes vir oorweging tydens die daaropvolgende projekfases bepaal. Die konseptuele ontwerpinstrument bied 'n reeks opsies (wat konsepopsies genoem word) en oorweeg 'n aantal insette, waaronder verskillende vaartuiggroottes en wisselende jaarlikse deurvloeie. Belangrike uitvoeropsies word dan opgestel in terme van die aantal vasmeerplekke, die aantal en kapasiteit van die eindpunt se hanteringstoerusting en die uitleg en die oppervlakte van die stoorwerf.

Gegewe die generiese en buigsame aard van die konseptuele ontwerpinstrument is dit in Microsoft Excel ontwikkel, en word daar in die konseptuele ontwerp van droë grootmaateindpunte vir die uitvoer en invoer van enkelprodukte voorsien. Die konseptuele ontwerpinstrument is modulêr van aard, met elk van die drie modules wat 'n gedeelte van die droë grootmaateindpunt dek, naamlik:

- Module 1 – Seekant se hantering en uitleg;
- Module 2 – Landkant se hantering en uitleg; en
- Module 3 – Stoorwerf se hantering en uitleg.

Verskeie toetsgevalle is uitgewerk, met altesaam 7 eindpunte (6 operasionele en 'n konseptuele een) wat vir 'n vergelykende ontleding gekies is. Die doel van die konseptuele ontwerphulpmiddel is nie om 'n enkele of deterministiese uitset te lewer nie, maar om 'n reeks uitvoeropsies te bied. Die projekontwikkelaar(s) kan dan, gegewe die eienskappe van 'n spesifieke projek, die opsies oorweeg. In die algemeen is bevind dat die konsep-opsies wat bepaal is, die operasionele uitlegte vir bestaande droë grootmaateindpunte insluit, asook addisionele opsies vir oorweging. Verder kan die konsep-opsies wat deur die konseptuele ontwerpinstrument bepaal word, ook deur projekontwikkelaar(s) en modelgebruiker(s) as 'n reeks (uitvoerbare) opsies vir verdere evaluering tydens die daaropvolgende detailontwerp of opgraderingsfases oorweeg word.

Die konseptuele ontwerphulpmiddel kan verskeie konsep-opsies vir verskillende insette lewer en word slegs deur die invoer beperk wat deur die modelgebruiker gedefinieer word. Die konseptuele ontwerpinstrument kan egter uitgebrei word vir toekomstige studies om verskeie goedere tegelyk te kan hanteer, die insluiting van stoorwerfbane met verskillende lengtes en/of breedtes en die insluiting van aanvanklike vereistes van kapitaaluitgawes vir elke infrastruktuur-element. Hierdeur word voorsiening vir 'n kostegedrewe optimalisering van die konseptuele ontwerp gemaak

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List of Abbreviations

BHP	BHP Billiton
BHP OHDP	BHP Billiton Outer Harbour Development Project
CAGR	Compound annual growth rate
dwt	Dead weight tonnes
FMG	Fortescue Metals Group
IAR	Inter-Arrival-Rate
IAT	Inter-Arrival-Time
kg	kilograms
m	metres
MTL	Million tonnes loaded
MTPA	Million tonnes per annum
PIANC	World Association for Waterborne Transport Infrastructure previously referred to as Permanent International Association of Navigation Congresses
PWCS	Port Waratah Coal Services Limited
RBCT	Richards Bay Coal Terminal
RHI	Royal Hill Infrastructure
t/h	Tonnes per hour
TAT	Total Available Time
TOT	Total Operating Time
UNCTAD	United Nations Conference on Trade and Development
UTL	Utilization Level
wt/st	waiting time / service time ratio

1 Introduction

This section provides the thesis title in section 1.1, provides a general introduction to the thesis background in section 1.2, indicates the objective in section 1.3 and the scope and exclusions in section 1.3 and ultimately gives an overview of the layout of the thesis in section 1.4.

1.1 Thesis title

Conceptual design of dry bulk terminals

A study into current dry bulk terminal design approaches and the development of a tool or calculation aid for the conceptual design and configuration of dry bulk terminals.

1.2 Background

Current demands for energy and mineral resources such as iron ore and coal have increased more than seven-fold from 448MTL (million tonnes loaded) in 1970 to 3,210MTL in 2018 (Statista Transport and Logistics, 2018). This dramatic increase over the last 50 years along with the associated increase in vessel sizes has resulted in the need for the construction of new dry bulk terminals or the expansion and optimisation of existing terminals.

Bulk terminals, as the name implies, are primarily used for the export, import or transhipment of bulk commodities. Bulk commodities are commodities that are loaded or discharged in a loose or fluid form (UNCTAD, 1985) and more specifically, bulk commodities comprise liquid bulk and dry bulk. While liquid bulk typically requires storage in tankers and comprises oil and petroleum products, dry bulk can be categorized into two primary categories, viz:

- major bulks; and
- minor bulks;

Major bulks comprise iron ore, coal, grains, bauxite/alumina and rock phosphate and account for nearly two-thirds of the global dry bulk trade. Minor dry bulks comprise, *inter alia*, steel products, sugars, cements and fertilizers and make up the remaining third.

Current analytical design guidelines such as those proposed by UNCTAD (1985) and at a high-level by Ligteringen and Velsink (2012), are limited in terms of the deterministic prediction of the design and spatial requirements, and do not present a comprehensive guideline for an end-to-end design of a dry bulk terminal. Although the aforementioned design guidelines currently exist, these guidelines are also not definitive enough to capture the planning, site selection, vessel sizing, annual throughput and throughput peaks, handling equipment and storage considerations required for the design of a specialised dry bulk terminal.

However, some authors, such as Van Vianen (2015) and Kleinheerenbrink (2012) have developed simulation driven and computer based tools respectively, these approaches do not appear to allow for the rapid determination of a wide range of feasible options that project developers may consider.

1.3 Objective

The present study is aimed at using available dry bulk terminal design approaches for the development of a new conceptual design tool to rapidly generate a range of key output parameters that may be considered during project feasibility prior to detailed design stages.

The new conceptual design tool should be generic enough to cater for a range of throughputs, shiploader configurations, stockyard machinery configurations and landside equipment configurations and should provide a range of outputs for each major infrastructure element of a dry bulk terminal. For example, for the seaside infrastructure aspect of a dry bulk terminal, the new conceptual design tool should be capable of generating a number of viable outputs in terms of the required number of berths and berth-side equipment based on a varied annual throughput, varying vessel sizes and a desired maximum berth utilization. Similarly, for the stockyard infrastructure aspect of a dry bulk terminal, the new conceptual design tool should be capable of generating a number of viable outputs in terms of the number of stockpile rows, the area of the stockyard and the number and capacity of stockyard handling machinery based on a varied annual throughput value and a desired stockyard capacity.

The objective of this study is to demonstrate a review of the current design approaches for dry bulk terminals, and further develop these approaches via a computer-based Microsoft Excel conceptual design tool. This new conceptual design tool should be capable of rapidly demonstrating, based on varying inputs, a wide range of preliminary spatial and technical viable output parameters to assist consultants, advisors, developers, financiers, governments, and port authorities during the conceptual design phase.

1.4 Scope and exclusions

Scope

The following is included in the scope of the present study:

- An assessment of current dry bulk terminal design guidelines;
- The development of a new computer-based conceptual design tool for import and export coal and iron ore terminals for multiple grades of ore to rapidly establish and assess a range of options that include the following parameters:
  - the number of berths and the berth utilization;
  - the required sea-side handling capacity for loading / unloading of vessels;
  - the stockyard size, configuration and area;
  - the number and capacity of stockyard handlers; and
  - the number and capacity of landside handlers.
- The new computer-based conceptual design tool is to be built Microsoft Excel, targeted towards project development parties including consultants and advisors to rapidly establish and assess viable terminal parameters and configurations.
- The new conceptual design tool can be made available in the form of a Microsoft Excel spreadsheet.
- The testing of the new computer-based conceptual design tool outputs against the proposed design parameters of a dry bulk terminal project that is currently at feasibility stage; and
- The testing of the new computer-based conceptual design tool against operational export and import terminals in selected locations across the globe.

Exclusions

The following aspects are excluded from the scope of the present study:

- All marine and seaside port design aspects, including the design of the:
  - approach channel and turning circle;
  - breakwaters;
  - port basins;
  - berth and/or jetty configurations and

  - any aids to navigation.
- All hinterland transportation modes, including for rail transportation methods, the design of the:
  - railway systems;
  - shunting yards; and
  - the number and capacity of tipplers.
- Incorporation of specialities such as the weighing and blending bulk commodities given that these are not primary functionalities of typical bulk terminals;
- All horizontal and vertical transportation methods within the terminal, including:
  - the design, sizing and specificities of bulk handling machinery;
  - capacity of conveyor belts and conveyor belt networks;
- the design of terminals that require the storage of perishable dry bulk materials within enclosed warehouses and silos, or the design of dry bulk terminals that cater for perishable bulk;
- Transhipment terminals where there may be both import and export activity; and
- The simulation of the events that would typically occur at a dry bulk terminal, including the stochastic arrivals of vessels, the variations in the time spent loading/unloading vessels, the flow of material through the terminal and the time that material is spent in storage in stockpiles. It should be noted that an end-to-end simulation of the entire logistics chain of a dry bulk terminal is typically undertaken during detailed design phases.

1.5 Layout of the Thesis

The contents of the thesis (the ‘Thesis’) are listed below

- Section 1 provides an introduction to the Thesis, outlines the background and objective and details the scope and exclusions;
- Section 2 outlines the literature review, which summarises the background to dry bulk terminals, describes their typical layouts, components and processes. Section 2 also details the variables that terminal developers may consider in the conceptual design stage of a dry bulk terminal and provides a review of selected simulation-integrated and dry bulk terminal conceptual design tools previously developed by others;
- Section 3 describes the methodology adopted for the development of the new computer based conceptual design tool, including the general approach and the modular approach, the key inputs and the assumptions and limitations;
- Section 4 provides an analysis of the outputs of the new conceptual design tool for a test case project that has not yet been built and is still in conceptual design stage;
- Section 5 summarizes the outputs of the new conceptual design tool in comparison to a number of well-known operating dry bulk terminals around the world; and
- Section 6 concludes the Thesis and provides recommendations for future research.

2 Literature Review

This section outlines the literature review undertaken for the Thesis. The section commences with a background in Section 2.1 and describes dry bulk terminals and their role in Section 2.2. Section 2.3 provides details on dry bulk commodities, while Section 2.4 provides context on the layout and components of typical dry bulk terminals. Section 2.5 provides an overview of typical dry bulk vessels. A number variables for consideration in the concpetual design of typical dry bulk terminals are highlighted in Section 2.6, while theoretical conceptual design approaches are discussed in Section 2.7. Section 2.8 provides a review of simulation-integrated and conceptual design approaches developed by others and the salient feautures of selected dry bulk terminals are presented in Section 2.9. Finally a summary of the literature review is included is Section 2.9.

2.1 General

2.1.1 Background

Dry bulk trade globally in 2017 was circa 4.3 billion tonnes which accounted for over 35% of all world seaborne trade. By weight, shipping of three of the five main dry bulk materials (iron ore, coal, and grain) represented over 27% of all world seaborne trade in 2017 and around two-thirds of all dry bulk trade (PIANC, 2019).

Current demands for energy and mineral resources such as iron ore, coal as well as that of grain have increased dramatically since the 1970's, with some estimates setting this increase to be around six-fold (UNCTAD, 2017) while others estimating it to be in excess of seven-fold. In order to cater for growth in demand, the construction of new terminals or the expansion and optimisation of existing dry bulk terminals is being considered by many port authorities, port owners / concessionaires and governments globally.

Current analytical methodologies such as those proposed by UNCTAD (1985) Ligteringen and Velsink (2012) are limited in terms of a deterministic prediction for the design and spatial requirements of each of the major elements in a dry bulk terminal. Analytical design methods often do not accommodate for the variations in the spatial and topographical restrictions imposed on the proposed constructions or expansions of dry bulk terminals. In addition, design methods are not geared to accommodate both spatial and environmental restrictions that are typically imposed on construction or expansion projects.

2.1.2 Driving forces

The question thus needs to be posed:

"What drives the need for current design approach and methodology to be reviewed?"

PIANC (2019) indicates that prior to 2018, existing guidelines for the planning and design of specialist marine terminals for the import and export of bulk solids were acknowledged to be outdated and are thus unable to provide a comprehensive and clear indication of the requirements of a dry bulk terminal of the future.

Furthermore, upwards trends in the demand for mineral and energy resources which have been fuelled by a decade of two-digit annual economic growth by China and much of the Far East continues to ensure that the need for larger and more efficient export terminals in resource-rich emerging markets is ever-present. This can clearly be seen from the data presented by UNCTAD (2017) where the international seaborne trade for major bulks (comprising iron ore, grain, coal, bauxite, alumina and phosphate rock) has grown from 448 million tonnes loaded (MTL) per annum in 1970, to 3,172MTL in 2016 (Figure 2-1); an implied compound annual growth rate (CAGR) of circa 4.3%.

Adding to the need for improved efficiencies at dry bulk terminals, more recent indications are that international cargo flows will expand across all segments in the upcoming years, with containerized and major dry bulk commodities trades still the forerunners, recording the fastest growth despite the fact that China's demand over the last three years (2017 – 2019) has, to an extent, decreased . Van Vianen (2015) explains that despite this increase of seaborne trade flows for bulk commodities, the shortage of port and storage area and efficient operations have become an apparent bottleneck. Additionally, the majority of modern optimisation efforts have been directed towards enhancing the efficiencies in container handling operations resulting in the need for more focused research towards the design of dry bulk terminals and optimisation of storage capacities.

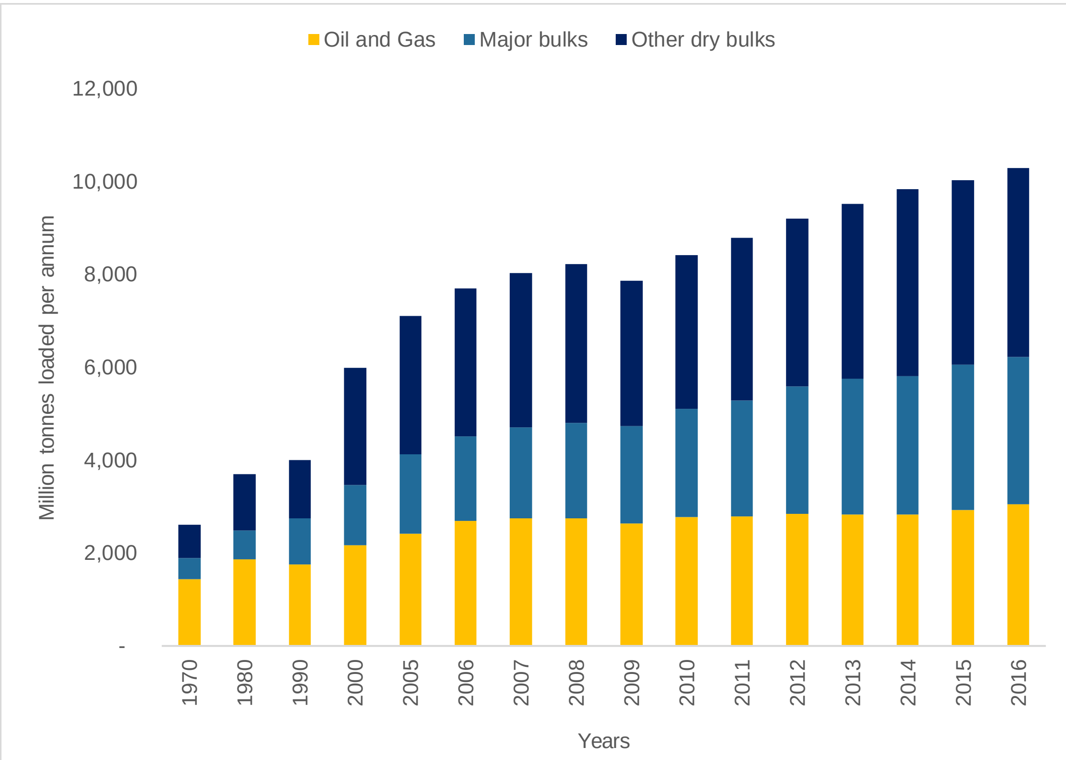

Figure 2-1: Growth in international seaborne trade (MTL per annum)

(Source: UNCTAD, 2017)

2.2 Role of dry bulk terminals and their development

2.2.1 Role and importance

Dry bulk terminals are used all around the world to handle large quantities of the bulk materials, including coal and iron ore and grain. Lodewijks *et al*. (2007) explain that the purpose of bulk terminals is also to act as a buffer between "either international or intercontinental transportation and inland or domestic transportation" of commodities. Terminals can play a combination of, or all of the following roles (Frankel *et al*., 1984):

- Cargo loading and unloading;

- Cargo bulking and consolidation;
- Cargo storage, classification and reclassification through blending;
- Intra-regional and inter-regional cargo transfer;
- Vehicle marshalling and cargo stowage;
- Physical form-change of cargo, from loose to bagged cargo; and
- Packaging of cargo.

Bulk terminals play an important role in the economic development of the country or region which they provide access to, and hence are often termed as the “key node” within the transport chain. In addition, terminals are also the linkage point between producers and end-users, and their efficiency, operational performance and subsequent tariffs have a knock-on effect on the overall transportation cost that is ultimately passed on to the end-users.

The productivity of bulk terminals, and thus their efficiency is determined by any combination of the following:

- the number and capacity of the various infrastructure components, including the landside and sea-side infrastructure;
- the number, efficiency and experience of personnel working within the terminal;
- the storage area and configuration for the bulk commodity itself;
- the availability and utilization of the movable equipment and machinery; and
- the overall operational approach implemented by the managing organization / port operator / owner and or investors.

2.2.2 Design and development of dry bulk terminals

In relation to the position of a dry bulk terminal in the full transportation chain, it is important to consider various aspects, both in relation to the desired bulk material to be imported/exported and the desired size and capacity of incoming/outgoing vessels.

Planning considerations should thus be two-fold:

- Demand and throughput considerations; and
- Vessel considerations.

Demand considerations should include the primary product or commodity type and its forecast volumes over the short, medium, and long-term future of the port.

Vessel considerations should include the potential changes in sizes and designs, and a combination of product and vessel considerations should include improvements and changes in loading / unloading methods and equipment, given the impact of technology and innovation prevalent in the 21st century (PIANC, 2019).

These two considerations impact both the design of the terminal intake and outtake areas, and the sizing and configuration of the stockyard area which are crucial elements during the construction or expansion of a dry bulk terminal. An undersized stockyard and/or terminal may result in excessive ship waiting times and may force terminal operators to pay penalty costs (or demurrage) to ship owners. On the other hand, an oversized terminal and/or stockyard may hinder the efficient recovery of the initial investment costs and result in overall poor operational efficiency.

2.3 Dry bulk commodities

2.3.1 General

Dry bulk commodities are commodities that are loaded or discharged in a loose or fluid form (UNCTAD, 1985). Bulk commodities comprise liquid bulk and dry bulk, with dry bulk comprising major bulk and minor bulk. As discussed in section 1.2, major bulks comprise of five commodities, namely iron ore, coal, grains, bauxite/alumina and rock phosphate while minor dry bulks comprise of sugars, cements and fertilizers.

Bulk commodities may also be categorized as perishable or non-perishable commodities, with perishable commodities (such as iron ore and coal) typically being stored in open-storage facilities, while non-perishable commodities are often stored in covered facilities such as warehouses or silos.

A description of two of the world's most common major bulk commodities (i.e. steel and coal) is provided in the following sections.

2.3.2 Iron ore

Iron ore is one of the world's most widely used resources, as it is transformed into steel which is used in the construction of almost all structures, vehicles, ships, airplanes and household appliances. Iron ore includes several ore types hematite magnetite, limonite, siderite and roasted iron pyrites (UNCTAD, 1985) and occurs in its oxide, carbonate, sulphate and silicate forms.

As the mining process of iron ore requires significant investment in both the core mining infrastructure as well as the associated transport infrastructure such as railways and port terminals, it is highly capital intensive and thus the iron ore mining industry is concentrated in the hands of a few major global players. Amongst these are multinational mining giants such as Rio Tinto, BHP Billiton and Vale S.A, with the former two accounting for 70% of total global production (Okoro *et al*., 2016). According to Okoro *et al.* (2016), iron ore is currently mined in about 50 countries across the world, but over the past decade, the primary exporters of iron ore were from Australia, Brazil, South Africa, India and Ukraine.

Iron ore is transported in bulk via dry bulk vessels and miners are linked to their markets by purpose built iron ore terminals that are increasingly required to accommodate ever-increasing vessel sizes. According to UNCTAD (1985), iron ores are generally dusty and thus the greenfield iron ore terminals are required to be located strategically to mitigate potential environmental impacts. Terminals may also be required to provide dust extraction or dust suppression equipment to reduce the effects of dust pollution, and in instances where overland conveyor belts traverse longer distances, the conveyor systems tend to be covered to minimize dust pollution.

Iron ore is typically stockpiled in windrows within a stockyard, with stockyards almost always being required for export terminals to provide the necessary surge capability (or otherwise termed as peak effects) to cater for intermittent vessel arrivals (UNCTAD, 1985).

2.3.3 Coal

Coal, in conjunction with iron ore, is amongst the most widely traded dry bulk commodities globally. Coal has a variety of uses, with the most common being its uses in the steelmaking process or in electricity generation. Two primary types of coal are used for each of these processes respectively, metallurgical coal and thermal coal.

Metallurgical coal or coking coal is known to have a relatively higher energy and a lower moisture content and is used as an essential fuel and reactant in the blast furnace process to make iron, steel and other similar metals. As such, demand for coking coal is intrinsically linked to the global demand for steel as approximately 780kg of coking coal is required to be used in the process of producing a single tonne of steel (Australian Government Department of Industry, Science, Energy and Resources, 2020).

Thermal coal, also sometimes referred to as steaming coal, is known to have a relatively lower energy content but a higher moisture content and is used in electricity generation. Thermal coal is burned to generate steam that powers turbines that generate electricity in coal-fired power stations and accounted for 45% of power generation globally in 2018 (Australian Government Department of Industry, Science, Energy and Resources, 2020).

The largest coal producer in the world is China, followed by India and the United States but the largest coal exporters in the world are Indonesia and Australia who when combined make up 50% of the total coal exports globally (Workman, 2020). Other large coal exporters are Russia, the United States of America, South Africa and Canada.

2.4 Dry bulk terminal arrangements and associated infrastructure

2.4.1 General

In general, the function of dry bulk terminals, as is the case with all terminals, is to fulfil three primary objectives; the handling, storage and the testing and sampling of bulk commodities. Bulk terminals are often termed as the “key node” within the transport chain. In the overall “mine-to-market” transport chain the dry bulk terminal is the key interface, both at the end of the export transport chain, or at the commencement of the import transport chain as shown in Figure 2-2

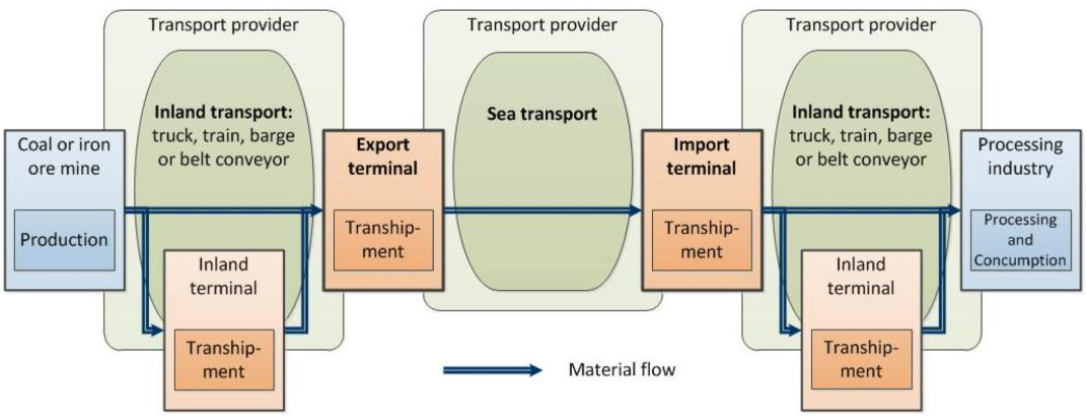

Figure 2-2: Dry bulk transport chain
(Source: Kleinheerenbrink, 2012)

For bulk terminals, the components required to fulfil the aforementioned objectives are specialised and require further analysis. It is thus deemed best to initially assess the layout arrangements of a dry bulk terminal. The various processes and infrastructure that supports the flow of bulk material through such a layout are therefore considered after the layout is determined.

Bulk terminals are either import terminals, or export terminals (or more simply, unloading and loading terminals respectively), or a combination of import and export in the form of a rarer multi-purpose import/export/transhipment terminal. Therefore, the direction of flow of the bulk material differentiates the two primary terminal types.

Because of varying ownership models and additional specific requirements in relation to commodity blending, bulking or consolidation, although import and export terminals are inherently similar, they may be designed slightly differently from each other. However, in general, both export and import terminals have three primary elements:

- a commodity intake area;
- a commodity storage and handling area; and
- a commodity outtake area.

The flow of material is illustrated in Figure 2-3. For an export terminal the flow commences at the landside intake area (where railway tipplers and truck deliver the material) and terminates at the sea-side area (where vessels exit towards the market). The reverse flow applies for an import terminal. On rare occasions, terminals may have dual functionality as transhipment terminals with their primary aim being commodity blending and consolidation.

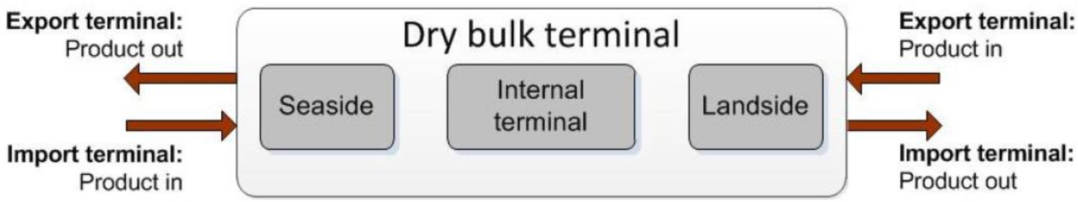

Figure 2-3: Typical terminal layout

(Source: Kleinheerenbrink, 2012)

2.4.2 Export dry bulk terminals

Export terminals are located in close proximity to either major transportation infrastructure or the source of the commodity (i.e. the mine or pit) and are focused on ensuring that the “pit-to-port” logistical chain is completed, to facilitate the outgoing flows of material (Wu, 2014). Export terminals are generally situated in countries that are net exporters of bulk material, such as Australia, Brazil, South Africa, Indonesia, Russia and Canada, which are some of the largest export markets of iron ore and coal (Van Vianen *et al*., 2011).

Export terminals are also traditionally built for the handling and export of a single or a very limited number of commodity types, due to their location and/or ownership (Wu, 2014). Examples of single use terminals include Richards Bay Coal Terminal in South Africa (coal export terminal, Port of Newcastle, Australia (coal export terminal) Port of Port Hedland in Australia (iron ore export terminal), and Ponta Da Madeira in Brazil (iron ore export terminal).

2.4.3 Import dry bulk terminals

Conversely, import terminals are situated in “net importer” countries, such as China, much of Europe and the US, and are usually required to handle multiple types and grades of bulk imports. This results in the increased complexity of spatial allocation and the design of both waterside and landside services. Examples of import terminals include the EMO terminal at the Port of Rotterdam (coal and iron ore import), the coal and iron ore import terminal at the Hansapoort Terminal at the Port of Hamburg and the coal import terminal at the Port of Antwerp

Import terminals are typically located in commercial or industrial hub ports and unlike export terminals, they are rarely located at remote port sites. The location of import terminals is largely driven by a pre-existing consumer base of a large city, availability of skills and energy for processing and packaging and access to inland intermodal transport (PIANC, 2019).

Import terminals may have smaller storage facilities than export terminals and may also be much more diverse, both in location and product types, and sometimes also in their cargo handling systems.

2.4.4 Dry bulk terminal infrastructure and processes

Dry bulk terminals, like other port terminals, function as a system to enable the smooth movement and storage of commodities. To be able to fulfil this function, a dry bulk terminal needs to have in place two key elements:

- 1) The requisite infrastructure comprising of, according to Ligteringen (1999):
  - Wet infrastructure
  - Dry infrastructure;
  - Terminal equipment; and
  - Terminal superstructure.
- 2) Robust processes and qualified human resources to fulfil the function of efficient commodity storage and movement.

The present section provides a high-level overview of these two elements.

2.4.4.1 Dry bulk terminal infrastructure

Wet Infrastructure

As outlined by Ligteringen (1999), the infrastructure comprises the wet and dry infrastructure, the superstructure and the terminal equipment, all augmented by the use of qualified human resources.

The wet infrastructure comprises the harbour basin in which one or more berths are located to accommodate the berthing of vessels. The harbour basin contains the dredged areas (e.g. approach channel, turning cycle, and basin) and may also contain other coastal management structures. The type of berthing configuration chosen by the port developer is largely dictated by the bathymetry of the port location.

In the context of dry bulk terminals, berth configurations may also be impacted by the size and type of vessels that may dock there, and the nature of the loading/ unloading process. In some instances, a typical arrangement of a marginal quay berth is employed, where the berth forms part of the terminal, but in other instances, berths are placed offshore. According to Tsinker (1997), regardless of the type of offshore berth, the main elements typically include a pier or loading/unloading platform combined with mooring and breasting dolphins. An access trestle then links the berth to the shore and the terminal beyond.

An outline of several typical berth configurations for dry bulk terminals is described below:

- Marginal quay berths:
  - Marginal quays are where the berth forms part of the terminal and the quay is connected to the landside portion of the terminal across its entire length. An example of this is the berthing configuration at the Richards Bay Coal Terminal (RBCT) in South Africa, as illustrated in Figure 2-4.
- Finger jetty or L-Jetty/T-Jetty berths:
  - Finger jetty berths are where the jetty extends away from the main terminal and into deeper waters, such that, in contrast to a typical marginal quay, a finger jetty may be used for the berthing of vessels on both sides. An example of this is the iron ore terminal at the Port of Saldanha Bay in South Africa, as illustrated in Figure 2-5.

- L-Jetty/T-Jetty berths are where the jetty extends away from the main terminal and into deeper waters, eventually forming a 'T' or 'L' at the end point, whereby vessels may berth alongside. These 'L' or 'T' shaped jetty configurations allows for a much deeper water depth without the need for extensive dredging closer to land, and this allows for vessels with larger draughts to berth, as the jetties typically extend a distance away from the shoreline into deeper waters. Moreover, should these be augmented with the installation of breasting dolphins and mooring dolphins (inclusively or separately in the form of a Lay-By berth), they may allow for the berthing of much larger vessels. In the case of the Lay-By Berth configuration, only ships that have they on-ship loaders/unloaders may be allowed to berth. An example of an L-shaped layout with a Lay-By berth can be found at the Port of Dampier as illustrated in Figure 2-6 and Figure 2-7 while an example of an T-shaped layout can be found in at Pier IV in the Ponta da Madeira Maritime Terminal, Brazil as illustrated in Figure 2-8.
- Material is typically transported from the jetty to the stockyard via conveyor belt systems.

Figure 2-4: Marginal quay layout - RBCT

(Source: Richards Bay Coal Terminal, 2011)

Figure 2-5: Finger jetty layout – Iron Ore terminal at the Port of Saldanha Bay
(Source: Transnet Port Terminals, 2013)

Figure 2-6: L-jetty with a lay-by berth – Port of Dampier
(Source: Rio Tinto, 2019)

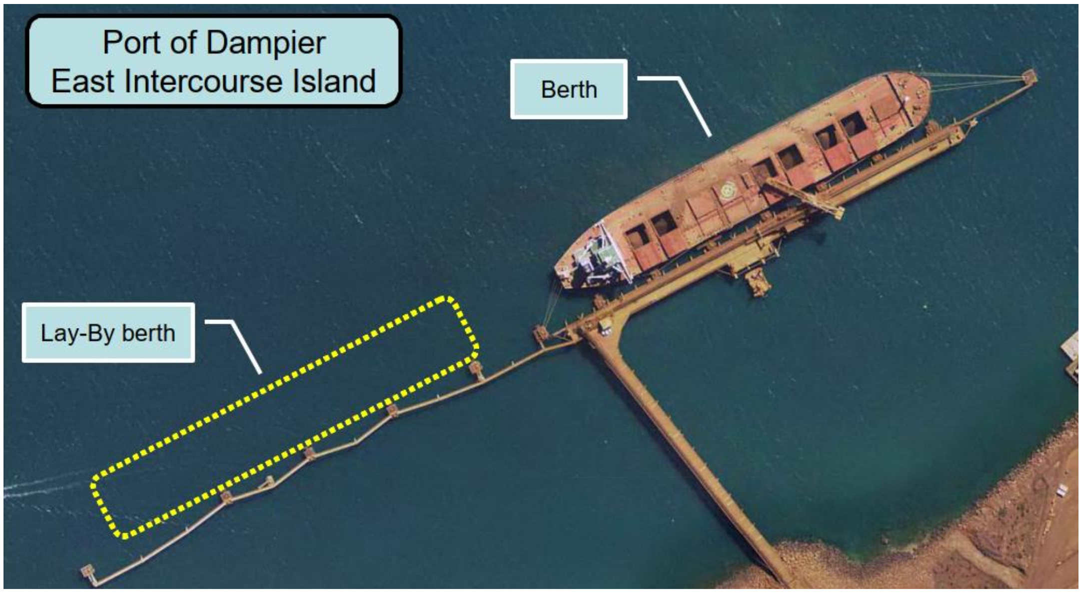

Figure 2-7: Aerial view of the L-jetty with a lay-by berth at the Port of Dampier
(Source: Rio Tinto, 2019)

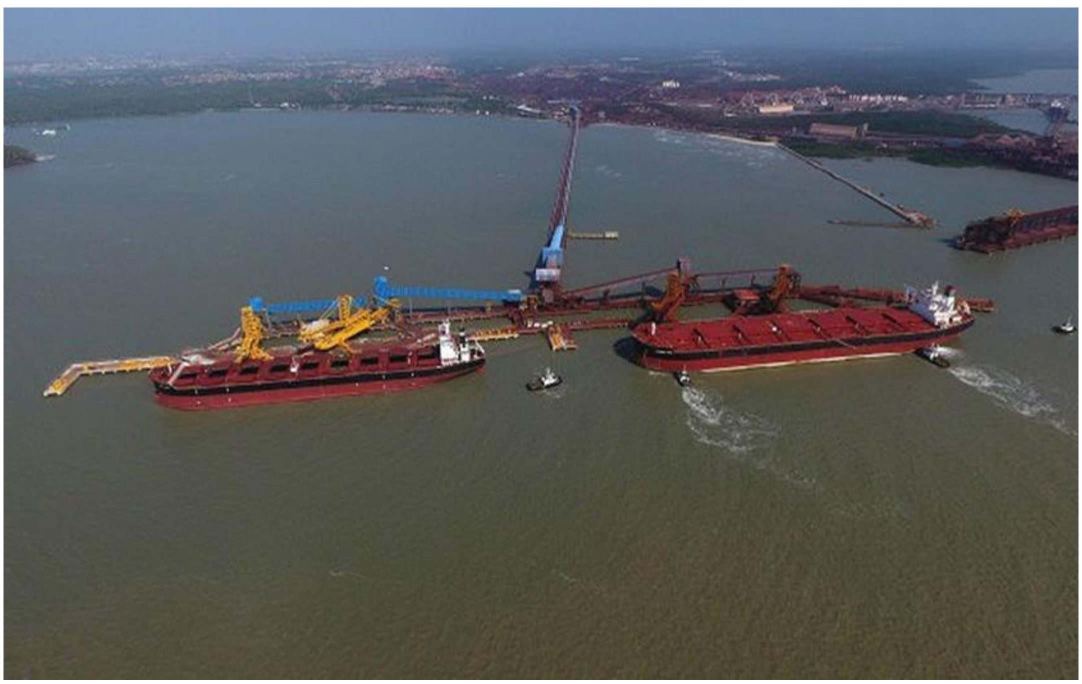

Figure 2-8: Aerial view of Pier IV at Ponta da Madeira, Brazil
(Source: The Maritime Executive, 2016)

Dry auxiliary infrastructure

In addition to the marine infrastructure, additional dry infrastructure is also required to ensure the completeness of the terminal system. Dry infrastructure comprises primarily of the auxiliary infrastructure that may not be marine related, and includes the following, *inter alia* (Aurecon AMEI, 2013):

- internal and maintenance roads;
- above and below rail assets and associated infrastructure from mine to the terminal (in the case of an export terminal);
- storage area pavements;
- foundations and drainage systems;
- provisions for telecommunications infrastructure;
- landside unloading facilities (explained in the terminal equipment subsection below); and
- internal transportation systems for the lateral movement of rail mounted gantry (RMG) cranes or ship-to-shore (STS) cranes (in the case of container terminals) or for stackers/reclaimers/shoreside loaders and unloaders (in the case of dry bulk terminals);

Further to the above, auxiliary infrastructure that is required for the functionality of the terminal includes, engineering services provisions for both supply and discharge such as, *inter alia*, (Thoresen, 2003):

- lighting and power supply facilities;
- potable and raw water supply facilities;
- sewage disposal facilities;
- stormwater disposal facilities; and
- other waste (such as oil and fuel) disposal facilities

Dry auxiliary infrastructure, although not considered to be purely port related, is required to be designed by qualified civil and structural engineers with marine related experience. The design and subsequent construction and operations of the aforementioned auxiliary infrastructure is key to the functionality of a dry bulk terminal but is not considered in the context of the conceptual design of a dry bulk terminal and its specific dry bulk related elements. However, the spatial considerations as a result of the required dry auxiliary infrastructure within a terminal should be included in the new conceptual design tool.

Terminal equipment

Terminal equipment is essential for the proper functionality of a terminal and is wide ranging in its capabilities and forms. According to Ligteringen (1999), terminal equipment may be fixed or mobile, with fixed equipment comprising belt conveyors and stationary cranes, while mobile equipment comprises equipment that moves via rail or road systems. In the context of dry bulk terminals, the following terminal equipment is required with each one briefly explained in Table 2-1:

Table 2-1: Terminal Equipment

Equipment	Description and commentary
Seaside handling equipment	• In general, handling equipment at the berths may either perform loading or unloading functions. • According to Ligteringen (1999), the capacity of the loading / unloading equipment is a determining factor in respect of the throughput capacity of a terminal. • The primary forms of unloading systems are: – Grab systems normally used for picking up commodities from within vessel holds and transferring it via hoppers onto belt conveyors; – Pneumatic systems which are either vacuum-based or pressure-based;

Equipment	Description and commentary
	– Vertical conveyors which include screw type vertical conveyors, chain conveyors or spiral conveyors; – Bucket elevators which comprises the continuously rotating bucket wheel, suspended from the boom attached to a travelling unloader. – Slurry systems; and – Self-discharging vessels. • The primary forms of loading systems are: – Travelling loaders; and – Slewing loaders or a combination of a travelling slewing loader.
Horizontal transportation systems:	• Horizontal transportation systems are typically belt conveyor systems. • According to Van Vianen (2015), belt conveyor systems are widely used at terminals for the continuous transport of dry bulk materials. Belt conveyors comprise of endless rubber belts, idlers to support the belt, a drive and tail pulley, a loading and discharge chute and a take-up system, enables the transport of material from an intake point to a discharge point. • According to Kleinheerenbrink (2012), conveyor belts for dry bulk commodities are mostly troughed in their design and depending on the belt width, material type and belt speed, large throughput rates of up to 15,000 tonnes per hour may be reached
Stockyard handling machinery:	• Stockyard handling machinery includes rail-mounted stackers, reclaimers or stacker-reclaimers of a multitude of variations. • According to UNCTAD (1985), convectional stackers or reclaimers are machines designed to be connected to belt systems to allow for the continuous stacking or reclaiming or bulk material in storage areas. • Typically, stackers/reclaimers or a combination of the two in a stacker-reclaimer system are allowed lateral movement via railway, which is positioned between stockpile lanes within in the stockyard. • Stackers / reclaimers / stacker-reclaimers may also move their booms vertically though luffing and may also be able to rotate slewing their booms. This arrangement may allow for one stacker / reclaimer / stacker-reclaimer to perform its function on two adjacent stockpile lanes.
Landside transportation and handling systems	• Landside transportation systems including road and railways infrastructure and road/rail loading and unloading systems. – Landside transportation systems: ○ Based on the throughput of the mine (in the case of an export terminal) or the size of the incoming vessel (in the case of an import terminal) the desired landside transportation mode(s) will be selected by the terminal developer. ○ Railway systems may be connected to an export terminal, such as in the case of the iron ore terminal at the Port of Saldanha, which is connected to the Sishen-Saldanha railway line, or Port Damper which is connected to the Hamersley & Robe River railway system. ○ Roadway systems or barge systems may also be employed, such as in the case of the barge loading system employed at the EMO terminal in

Equipment	Description and commentary
	the Port of Rotterdam, Netherlands or in the case of the barge unloading system employed at the Bontang Coal Terminal, Indonesia – Unloading systems for landside transport (in the case of export terminals): ○ For railcar unloading systems, the incorporation of components such as rotary tipplers, end dumpers or bottom discharge wagons may be employed. For large quantities the most common unloading method is rotary tippling where the tipplers unload wagons by turning then either 180° or 360°. ○ For road transportation unloading systems, trucks that are incoming may be self-unloading (such as typical back tippers or bottom dischargers) or non-self-unloading, which may require unloading via similar rotary tippling methods employed for rail wagons. – Loading systems for landside transport (in the case of import terminals): ○ According to Kleinheerenbrink (2012), the loading of trains is normally done by the use of hoppers which are filled by a belt conveyor connected to reclaimers in the stockyard. ○ The loading of trucks can be done with comparable systems and loading capacities as for the loading of trains.

(Source: Ligteringen, 1999)

Terminal Superstructure

According to Ligteringen (1999), the superstructure consists of the sheds and other covered storage spaces as silos (normally only for certain types of bulk, e.g. agribulk or alumina), offices, workshops and other buildings. The necessity of these facilities will depend on the envisaged product mix that the terminal will be handling and the processes that will be taking place on the terminal.

2.4.4.2 Dry bulk terminal processes

The process from arrival of the export material at the landside intake area of the terminal to seaside outtake area may be summarised into three distinct processes as illustrated in Figure 2-9

Figure 2-9: Dry bulk terminal processes

Augmenting the aforementioned processes, a typical layout for the handling bulk mineral resources in an export terminal is shown in Figure 2-10. Each of the processes and their respective sub-processes are also explained further in this section. It should be noted that the processes for an export terminal are explained, but the converse of these processes will be true in many aspects for an import terminal.

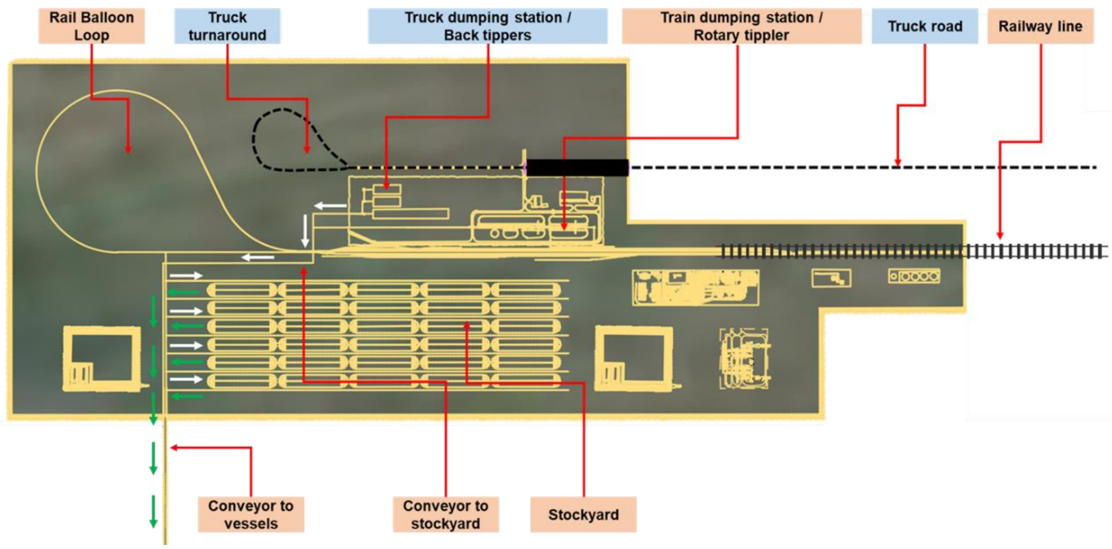

Figure 2-10: Conceptual export terminal layout and processes

(Source: Aurecon AMEI Pty Ltd, 2013)

Landside intake process:

The landside intake process may be divided into three sub-processes, listed below and explained in Table 2-2:

- Material arrival via road or rail;
- Material offloading; and
- Material transfer to stockyard.

Table 2-2: Landside intake process

Process	Details
Material arrival via road or rail	• Material is delivered to the export terminal by the landside transportation mode (road or rail). • As shown in Figure 2-10, the primary method for delivering material to the stockpile is by train or truck.
Material offloading	• Train offloading process: – Trains can enter the site and proceed to the train dumping station. – Wagons are emptied through the use of a rotary dump tippler where up to two cars can be locked down and rotated to deposit their load into hoppers beneath. – Modern tippler design allows for wagons that are rotated to remain engaged with the rest of the train through the use of couplers.

Process	Details
	– After discharging the material, the wagons continue forward to the railway balloon loop and exit at the same point that they entered. Typically, a double rail at the entrance allows for one train to enter as another leaves. • Truck offloading process: – Trucks enter through the primary access road, drive thorough the turnaround and proceed to one of three truck dumping stations. – The trucks drive directly onto dumper ramps and are secured. – When the truck is secured, a hopper cover opens, and the ramp tips the vehicle and dumps the load into the hopper. – The ramp is then lowered, and the truck driven off leaving the system ready for the next vehicle.
Material transfer to stockyard	• Material that is offloaded into hoppers (sometimes termed as material container bunkers) is transferred to a conveyor system beneath the truck and train dump stations. • The material travels on conveyors into various stacker reclaimer units that are found between the stockpile lanes • The stacker reclaimer is a key element of the stockpile operations but is not shown on the image • From the conveyor, the material travels into the stacker reclaimer and rises up to the stacker reclaimer boom until it is discharged from the tip of the boom to form the stockpile.

(Source: EMS Tech, 2014)

Stockyard handling process and storage:

The stockyard handling process and storage component may be divided into three sub-processes, listed below and explained in Table 2-3:

- Stacking process
- Storage
- Reclaiming process

Table 2-3: Stockyard handling process and storage

Process	Details
Stacking process	• Material flows from the incoming conveyors onto stacking conveyors. • The stacker conveyor feeds the material to its associated stacker (or the stacking function of a stacker-reclaimer), • The stacker may then point its boom towards an area where the stockpile is to be formed, and material is then discharged onto a stockpile where it is temporarily stored before shipment.
Storage	• Material is stored in the stockpile until it is ready to be exported (or imported).

Process	Details
Reclaiming process	• Stacker reclaimers use rotating bucket wheels at the end of the boom to draw the material into a chute and onto the conveyor which operates in the reverse direction to that used when stacking. • The boom slews and advances and cycles to reclaim each layer of the stockpile. • After a layer of material is retrieved the boom is lowered to reclaim the next layer. • The material then passes through a chute to the belt conveyor below and travels to the jetty by the jetty conveyor (sometimes termed as the outhaul conveyor). • After traveling along the outhaul conveyor, the material travels into the ship loaders, where it is loaded onto ships for the export market.

(Source: EMS Tech, 2014)

Seaside outtake process

The Seaside outtake process may be divided into two sub-processes, listed below and explained in Table 2-4:

- Material movement away from the stockpile; and
- Ship-loading process

Table 2-4: Seaside outtake process

Process	Details
Material movement away from the stockpile; and	• When the ship is ready to be loaded, the material is removed from the stockpile using a re-claimer (or the reclaiming function of a stacker-reclaimer) and loaded onto the re-claimer's conveyor. • A re-claiming conveyor, connected to the reclaimer will load the material onto a jetty conveyor; • Jetty conveyors may, at times, be enclosed to protect the material from the elements, particularly in cases where the berths are a distance away from the stockpile. • The jetty conveyor loads the material onto ship loading conveyors;
Ship-loading process	• Material from ship loading conveyors is transferred to ship-loaders; • Ship-loaders may be able to traverse alongside the berth, depending on their configuration; • Modern ship-loading technology has allowed for ship-loader discharge points to be fitted with hydraulic-controlled spouts, that are able to rotate and change trajectory and thus allow for the discharge of material into any direction within the ship's hold. • Once the ship has been filled, it can then be de-berthed and continue on to the export market.

(Source: EMS Tech, 2014)

2.5 Dry Bulk Vessels

2.5.1 General

Bulk shipping vessels range in size from barges that are relatively small to very large carriers that weigh in excess of 405,000dwt (dead weight tonnes). Generally, vessels are classified into five major vessel categories (PIANC, 2019):

- **Barges:** smaller vessels primarily used in trade along coastal towns and rivers or used in the transhipment of ore.
- **Product dedicated vessels:** vessels that have been dedicated to the transportation and/or transhipment of specific products. These products may include wood chips, cement or sugar, and as such these vessels may have unique specifications that enable the specific handling or these particular products.
- **Bulk carriers (i.e. multi-purpose carriers)**: general purpose ships with large holds suitable for the transportation of almost all bulk products. These vessels are typically designed for loading and unloading by shore-based equipment only, and thus may lack ship loading/unloading equipment.
- **Ore carriers**: specialist bulk ore carriers with smaller holds suitable for high density ores. Ore carriers typically may slightly have smaller draughts than typical bulk carriers.
- **Geared self-loading/unloading vessels:** bulk carriers that possess their own cranes and/or conveyor systems. This allows these vessels to load and/or unload without use of quayside equipment.

2.5.2 Size classification (dead weight tonnage)

Further to the above, and more relevant to this study are the common size classes of vessels. The size of these vessels is described by a number of parameters but the most common is the vessel's dead weight tonnage. A vessel's dead weight tonnage (dwt) is its total carrying capacity and includes the cargo being carried as well as additional consumables such as fuel and fresh water (Thoresen, 2003).

For most vessels the cargo carrying capacity is approximately equal to its dead weight tonnage, but in some instances during detailed design, a reduction factor of 95% of the dwt may be used to more accurately evaluate the tonnage of cargo being carried. However, for the purposes of consistency and simplification, the reduction factor is not used during conceptual design, or for the purposes of this study. According to PIANC (2019), the six common size classes and their associated dead weight tonnage ranges for dry bulk vessels are:

- **Handysize** vessels: 15,000 to 35,000 dwt;
- **Handymax** vessels: 35,000 to 60,000 dwt;
- **Panamax** vessels: 60,000 to 85,000 dwt;
- **Post-Panamax** vessels: 85,000 to 125,000 dwt;
- **Capesize** vessels: 125,000 to 220,000 dwt; and
- **Very Large Ore Carrier** (VLOC): greater than 220,000 dwt.

In respect of vessels that utilise general cargo loading/unloading facilities at terminals, the majority of the smaller vessels (< 15,000 dwt) are typically used along rivers and more often than not utilise general cargo facilities rather than specific dry bulk terminals. Typically, they carry locally consumed products such as cement and aggregates.

Some of the smaller Handysize vessels (< 30,000dwt) also dock at general cargo facilities when the facilities are equipped with mobile bulk handling equipment. In general, vessels with dead weight tonnage greater than 30,000dwt will dock at specialised dry bulk ports. According to PIANC (2019), circa 80% of the world's seaborne dry bulk trade is carried in vessels that are greater than 65,000dwt (Panamax and larger) in size.

2.5.3 Vessel dimensions related to the vessel size

Although the size classification of vessels in tonnage is important, the linear dimensions of a vessel also need to be considered in the design process of terminals. A vessel's measurement is expressed in 'metres' and includes three primary dimensions as listed below (Global Security, 2000):

- The length of vessel, including the most commonly used term 'Length overall' (LOA). The LOA is the maximum length of a vessel's hull parallel to the waterline (i.e. from the extreme forward end of the bow to the extreme aft end of the stern,
- The beam of vessel, sometimes referred to the Beam Overall (BOA). The beam is the overall width of the ship measured at the widest point of the nominal waterline.
- The draught (or draft) of vessel which is the vertical distance between the waterline and the bottom of the vessel hull (keel). The vessel draft is an important characteristic as it limits the depth of water that the vessel can safely navigate through.

Vessel dimensions are intrinsically linked to the load carrying capacity and need to be considered during the design of terminals as the variance in vessel dimensions impacts the layout of wet infrastructure as well as a number of marine specific aspects such as the approach channel, the size of the turning basin and the required depth of the port. Average vessel dimensions may also influence the selected location of a greenfield port and the maintenance requirements, due to the bathymetry constraints and amount and frequency of dredging required to maintain minimum port depths.

A number of studies have been undertaken on the global vessel fleet which includes vessels that have been scrapped and vessels that are in service. From these studies, the average dimensions of world bulk carrier fleet can be described as a function of vessels carrying capacities (in dwt). The findings of Kleinheerenbrink (2012) can be summarized by Equation 2-1 and Table 2-5, and the findings of Van Vianen (2015) can be summarized by Equation 2-2 and Table 2-6.

Equation 2-1: Vessel dimensions as a function of carrying capacity (Source: Kleinheerenbrink, 2012)

$$y = a_i x^{b_i}$$

where x is equal to the vessel carrying capacity in deadweight tonnes (kilotonnes – kt)

Table 2-5: Vessel dimensions as a function of carrying capacity

Vessel Dimension (m)	a_i	b_i	R-squared value
LOA	8.44	.29	0.96
Beam	1.21	.30	0.94
Draught	0.42	.31	0.96

(Source: Kleinheerenbrink, 2012)

Equation 2-2: Vessel dimensions as a function of carrying capacity (Van Vianen, 2015)

$$y = a_i \ln(x) - b_i$$

where x is equal to the vessel carrying capacity in deadweight tonnes (kilotonnes – kt)

Table 2-6: Vessel dimensions as a function of carrying capacity (Van Vianen, 2015)

Vessel Dimension (m)	a_i	b_i	R-squared value
LOA	65.5	50	0.96
Beam	12.7	20	0.94
Draught	4.1	4	0.96

(Source: Van Vianen, 2015)

By plotting the findings of the studies referenced above (i.e. the findings of Kleinheerenbrink (2012) and Van Vianen (2015), (Figure 2-11 and Figure 2-12) the following is observed:

- For vessel sizes between 20kt and 450kt, the average variance between the two studies is smaller than for vessel sizes between 0kt and 20kt and is, on average:
  - less than 1% for the LOA dimension;
  - less than 2.5% for the beam dimension; and
  - less than 6% for the draught dimension.

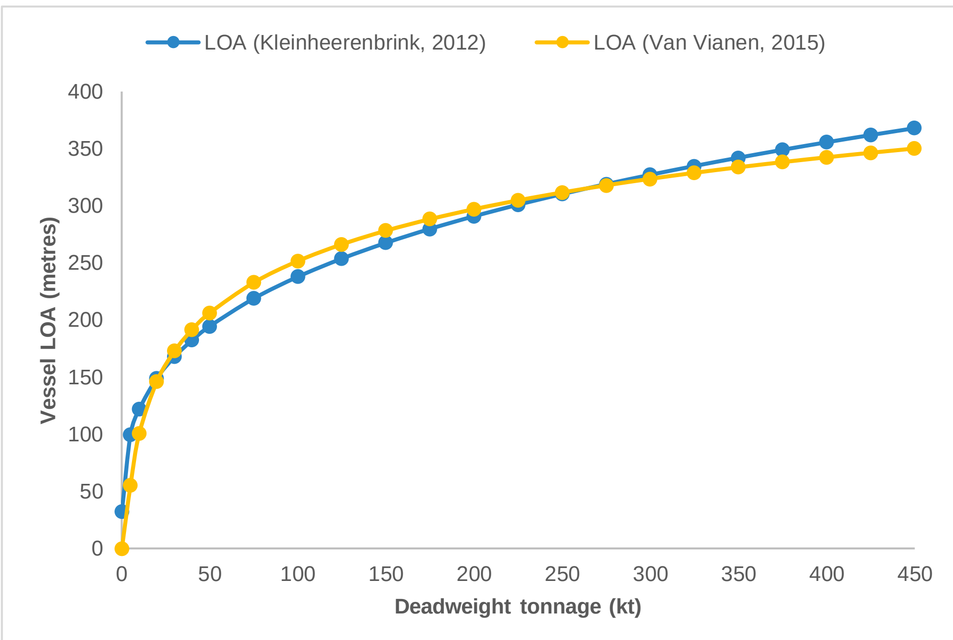

Figure 2-11: Vessel LOA (m), Kleinheerenbrink (2012) versus Van Vianen (2015)

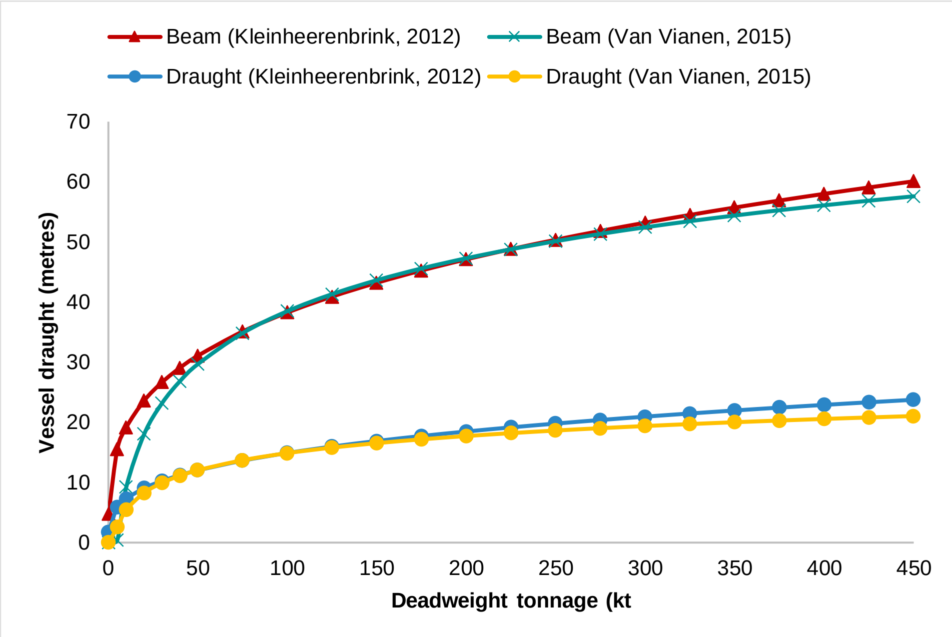

Figure 2-12: Vessel beam (m) and vessel draught (m), Kleinheerenbrink (2012) versus Van Vianen (2015)

2.6 Variables for consideration in the conceptual design of terminals

2.6.1 General

Dry bulk terminals (as is the case with liquid bulk, container and break-bulk terminals) sit at the interface between land-based transportation modes and the marine-based transportation mode and therefore the location and layout of this interface is key when approaching its design.

Although the design of a dry bulk terminal may not fundamentally influence the larger logistics chain, the approach to designing a dry bulk terminal must consider its place within that larger logistics chain, and according to the PIANC (2019), these design considerations include:

- The forecast volumes (of production, storage and demand) over the short, medium and long term;
- The type of product or products that will be core to that terminal,
- Potential trends in the size and design of typical vessels for the shipment of the core product/products;
- The type of terminal and the direction of flow of material (import or export);
- Cargo handling equipment and methods and trends in technology changes that may impact the spatial requirements for such cargo handling equipment; and
- Certain key environmental or social factors which should always be considered.

Key considerations and design variables affecting this planning exercise are detailed further in this section.

2.6.2 Stochastic effects

When designing a terminal system, there are both deterministic and stochastic variables that would need to be considered. For the sake of clarity, a deterministic system is a system in which no randomness is involved in the development of future states of the system. A deterministic system based on deterministic variables will thus always produce the same output from a given starting condition or initial state. On the contrary, a stochastic system is a system in which random processes are involved in the development of future states of the system. A stochastic system based on stochastic variables will thus produce the multiple different outputs from a variety of starting condition or initial state

In a deterministic setting, which typically is during the conceptual design phase, the averages of uncertainties may be taken. However, in some instances the average of a stochastic occurrence may result in a flawed output. Bot (2012) provides an extreme example whereby, if a particular terminal layout is chosen based on the premise that on average, a ship arrives every 24 hours, the terminal configuration will not be able to accommodate for an instance where two ships may arrive at the same time on the same day, while no ships arrive on the following day.

Examples of stochastic variables which may need to be considered during detailed design phases are, *inter alia*:

- Distribution in vessel sizes (should the vessel mix vary);
- Loading/unloading rate at the quayside;
- Berthing/deberthing time (termed as berth effects);
- Total time that a vessel may spend in port;
- Loading/unloading rate within the stockyard;
- Time that the commodity will spend in the stockpiles;
- The Inter-arrival-rate (IAR) of vessels; and
- The Inter-arrival-rate (IAR) of landside transport modalities.

The vessel Inter-Arrival-Rate (IAR) may be defined as the inverse of the vessel Inter-Arrival-Time (IAT). Vessel IAT is typically defined as the time difference between the arrival of consecutive vessels. In a deterministic or theoretical setting, the vessel IAT may be assumed to be constant, but in reality, the vessel arrivals are stochastic.

The aforementioned stochastic variables may cause ‘peak or surge moments’ and this must be considered during detailed design phases. However, in the context of the new conceptual design too, a ‘flexibility factor’ may be considered that will allow for deterministic outputs to cater for these anticipated variations, For example, Bot (2012) concludes that the storage capacity of the stockyard varies with the annual throughput capacity, with higher variations in terminals that have lower annual throughputs, in the following manner:

- A factor of 1.031 (or 3.1% increase) to be added for large terminals that are above 50 million tonnes per annum (MTPA), and
- A factor of 1.076 (or 7.6% increase) to be added for large terminals that are below 10 MTPA.

Although not specifically stated, it can be implied from the results of Bot (2012), that a peak factor calculated in proportion to the throughput may be added to stockyard capacities for terminals with throughput between 10 MTPA and 50 MTPA as the stochastic effects decrease as the terminal throughput gets larger.

2.6.3 Terminal Type

As outlined in section 2.4.2 and section 2.4.3, the selected type of terminal (import, export or transhipment) is a key input into the design process. Import terminals will usually benefit from being close to the end consumer of the imported product, while export terminals usually benefit from being located strategically, at the shortest possible distance from where main product exported is being sourced (i.e. mine, quarry, etc.).

In addition, the terminal type (import / export) has a multitude of previously set design precedents associated with it, including the following, *inter alia*:

- The minimum and maximum loading / unloading factors obtained as the ratio between installed capacities and minimum required capacities,
- The minimum and maximum quay length factors,
- The minimum and maximum storage factors;
- The rated capacity of seaside and landside loaders/unloaders;
- The through-ship efficiency factors; and
- The length to width ratios of stockyard areas.

2.6.4 Operating mode

PIANC WG 184 (2019) states that an important consideration that impacts the size of terminal is the operating methodology proposed by the terminal operator. This involves the following:

- Single product vs multi product terminals:
  - The number of products (different grades and sizes) stored on the terminal should also be considered. According to Ligteringen and Velsink (2012), the processes for blending of different grades are required, particularly for iron ore and coal terminals and as such, specific stacking and reclaiming methods across different stockpiles may be required. In general, the more products are handled at a terminal, the larger the required storage area (Lodewijks *et al.*, 2007).
- Single dedicated user vs multi- user terminals:
  - The storage area for a single-user terminal is governed by the requirements of that single user in relation to ship service times and intermodal transfers. In contrast, the storage area for a multi-user terminal requires reaching a compromise between the requirements of the various users (PIANC, 2019). An example of this is where a mining or a bulk material export company operates the entire logistics chain including the bulk terminal and might decide to allow for blending and long-term storage at the terminal because this may not be able to be undertaken at the bulk material source. However, a multi-user terminal might decide to decrease the available storage area based on the fact that products arrive to the port ‘preblended’ and pre-assigned to vessels and as such product dwell time in storage and long-term storage requirements may be reduced (PIANC, 2019).
  - In the case of single-user terminals, in general, as the owner/operator manages the intermodal transport assets, the ship arrival and departure patterns would typically be more controlled and as such, berth commitment levels may be higher than berth commitment levels for multi-user terminals (PIANC, 2019).

2.6.5 Demand forecasts and terminal throughput capacity

The demand forecast and the terminal throughput capacity is impacted by:

- the type of product,
- the direction of flow (i.e. import versus export);
- the average call size of vessels; and
- the frequency of vessel calls.

Usually, the demand forecast will be undertaken as part of the initial pre-feasibility and feasibility stages through the developing group’s financial/commercial workstream. A matured demand forecast should provide the necessary information on the commodity types and the typical vessel sizes that are forecasted to be handled by the planned bulk terminal.

2.6.6 Cargo handling considerations

In general, PIANC (2019) recommends that although the stockyard capacity will depend on product throughput, the number of products being handled, product segregation and blending requirements, and vessel and barge sizes calling at the terminal, and as a minimum, the stockyard capacity (for a transhipment terminal) should be at least double the largest size that will be loaded/unloaded at any time from ocean going vessels. However, for the design of any dry bulk terminal, it is critical that the following are quantified:

- the number of berths and the number of ship loaders/unloaders at each berth;
- the utilisation level and operational availability of equipment;
- the capacity and location of storage and stockpiling areas;
- the combined handling capacity of the terminal as a system, including:
  - the capacity of the seaside loaders/unloaders;
  - the capacity of the horizontal transport conveyor system;
  - the capacity of the stockyard handlers; and
  - the capacity of the landside handlers.

In addition, PIANC (2019) also indicates that although different methodologies may be considered to estimate the capacity of the bulk handling system at a terminal, the majority of these methodologies are based on assumptions that the overall handling capacity of the bulk handling system is a function of the system's utilisation/ occupancy level ('UTL'). UTL is defined as the total operating time (TOT) divided by the total available time (TAT) as shown in Equation 2-1.

Equation 2-3: Occupancy / Utilisation Level

$$Utilisation\ Level\ (UTL, \%) = \frac{Total\ operating\ time\ (TOT)}{Total\ available\ time\ (TAT)}$$

The Total Operating Time (TOT) or utilized time can be defined as the time when the system is in operation at full or partial rates.

The Total Available Time (TAT) can be defined as the sum of the following:

- **the unscheduled system downtime** defined as the operation downtime due to equipment breakdown or product flow interruption such as weather events, power failure, unscheduled equipment moves;
- **the total operating time**, as defined above;
- **the transit/set time**, defined as the non-operation time when equipment is waiting for transport modality (ship, barge, railcar, truck) to arrive/depart or the time that the equipment is being set in position, so that operations can commence; and
- **the idle time**, defined as the time that the system/equipment is not required for production or is unavailable due to other reasons such as personnel strikes, continued inclement weather conditions or force majeure events.

More simply, the Total Available Time may be defined as the total calendar time that the ship loader / bulk handling system is available less the scheduled downtime (where scheduled downtime includes time allocated for planned and preventative maintenance and is typically in the region on 20%). In general, it can be said that the utilization percentage of dry bulk handling equipment is normally less than 60%, as the operational availability is normally around the 80% mark. A summary of the above terms is shown in Figure 2-13.

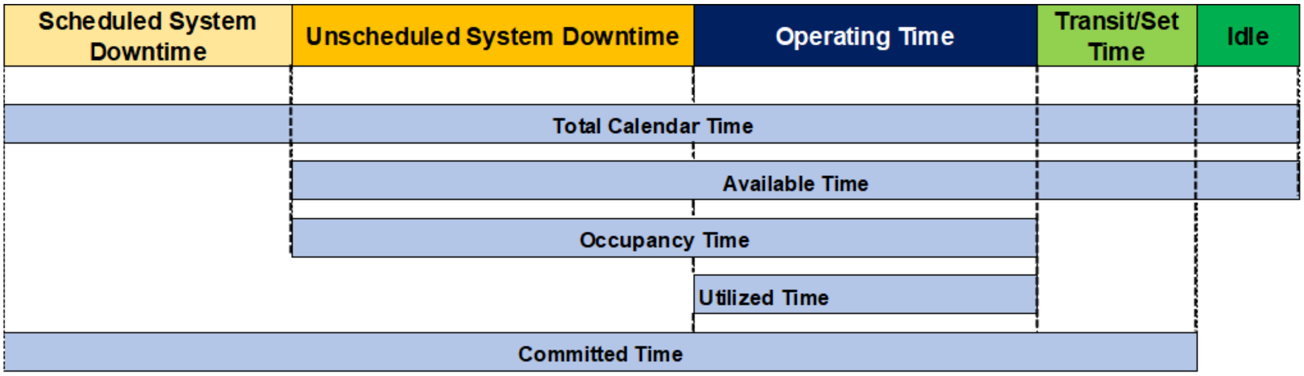

Figure 2-13: Illustration of system time commitments
(Source: PIANC, 2019)

Lodewijks *et al*. (2007) state that due to operational issues the average capacity, in the case of an iron ore handling facility in India, is about 46% of the maximum capacity, which in that author's opinion was typical for iron ore handling bulk terminals given that the global average capacity of ship loading equipment varies between 40% and 55%. According to PIANC (2019), when equipment surpasses a critical utilisation or occupancy level, problems often result as the terminal's ability to properly maintain the system and recover from unforeseen delays decreases with increasing equipment occupancy levels.

In the case of berth utilization or occupancy, Thoresen (2003) outlines that for container and conventional general cargo terminals, berth utilization limits usually depend on the port's ownership model and the control that the port's administration has over the arrival patterns of incoming vessels. Although not explicitly stated, the same applies for dry bulk terminals. Thoresen (2003) further details that for an average level of arrival control by a port's administration, berth occupancies should typically be below 65% for a terminal with five or less berths, and may, in some instances, reach up to 70% in the case of terminals with 6 or more berths and a higher level of arrival control by the port's administration. However, in a high berth occupancy scenario, ships will likely experience longer queues and more time waiting for service due to the terminal's decreasing ability to operate efficiently, thus increasing the likelihood of the terminal being liable for higher demurrage costs.

2.6.7 Waiting time vs Service time

In general and given that the inter-arrival-times (IAT's) of the vessels and vessel service times fluctuate stochastically, there can never be an instance where the occupancies at a berth exceed the range of 95%, without the vessel waiting times being exponentially large, as illustrated in Figure 2-14, adapted from UNCTAD (1985).

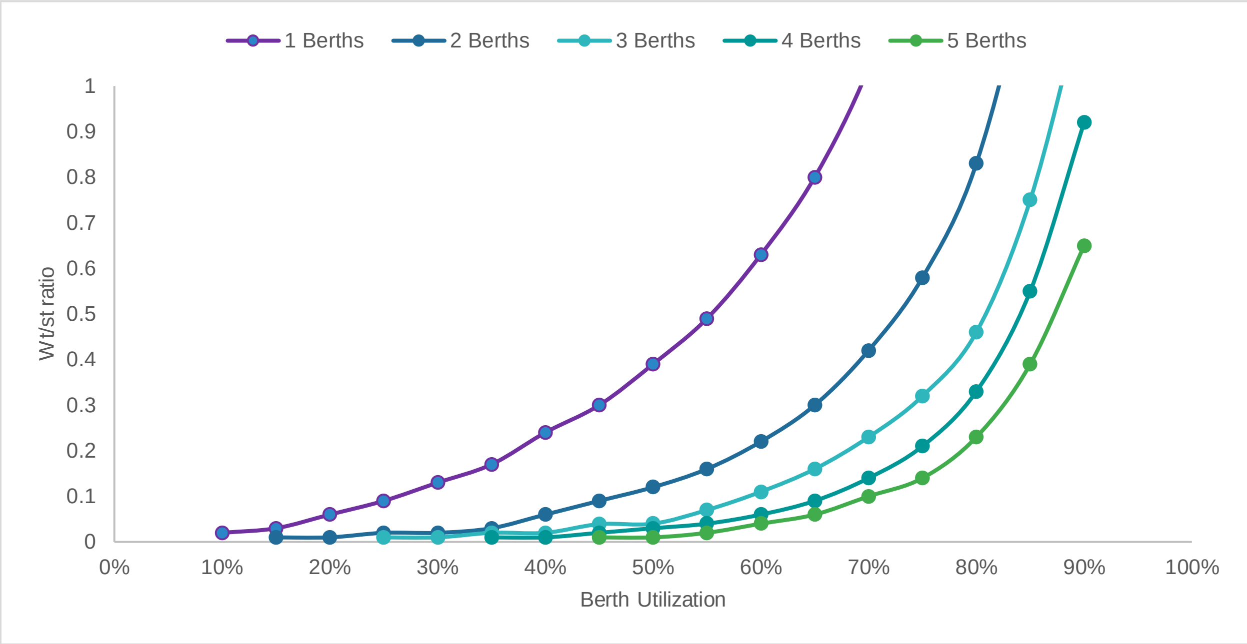

Figure 2-14: Waiting time to Service Time ratio in relation to average berth utilization
(Source: UNCTAD 1985)

Further, it is unlikely that vessels may never have to wait, or wait for a very minimal time, without having multiple additional berths for a given throughput. Thus, the middle ground would be for the port developer to obtain the between vessels waiting to berth (waiting time) and unoccupied berths. The relationship between the waiting time, and the time that a vessel spends on a berth (the service time) is termed as the waiting time / service time ratio or (wt/st).

According to UNCTAD (1985), a first estimate for dry bulk terminals based on a specific querying theory approach can be assumed. The wt/st ratio is widely used as a measure of the level of service provided by a terminal and is included as a port performance indicator by UNCTAD. It is usually considered that waiting time should be not more than 50% of service time (Kleinheerenbrink, 2012) and according to UNCTAD (1985), the economic optimum of the wt/st ratio is generally between 30% and 40%.

2.6.8 Vessel sizes

At the early stages of the terminal design processes, detailed vessel characteristics might not be readily available and are typically assumed in terms of the average and the range, from the smallest to the largest ship or barge transporting each commodity type (PIANC, 2019).

These vessels characteristics will influence several design parameters during the bulk terminal planning stage including:

- The physical marine access design, including the design of the navigation channel, the required depth at port and the associated dredging requirements, the wave protection measures and the need for any marine structures; and
- The number and the dimension of the berths including the correlation between the product handling capability of specific berths due to the handling equipment and the specific products being handled (i.e. even if all vessel traffic can theoretically be accommodated through one single berth, in the case of a

terminal handling more than one commodity, incompatibility between product types and handling equipment might require dedicated berths for each commodity).

2.6.9 Commodity types and characteristics.

For the land-side of the bulk terminal, for each commodity type identified for flow into or out of the terminal, the core commodities that have been indented should be further assessed in terms of their relevant material characteristics. These characteristics may include *inter alia* (PIANC, 2019):

- Bulk density:
  - Bulk density is defined as the ratio of the mass of one cubic metre of commodity to its volume including voids and moisture is shown in Equation 2-4.

    Equation 2-4: Bulk Density

    $$Bulk\ Density\ (\rho_b) = \frac{Mass\ (tonnes)}{Volume\ (m^3)}$$
  - This is an important factor in determining the amount of cargo that can be carried in a vessel.
  - It should be noted that that the bulk density for a bulk commodity in a stockpile differs from the actual in-situ particle density of that commodity, due to the presence of void spaces and moisture (Scogings, 2015)
- Particle size distribution as the particle size may affect the materials handling method:
  - The transportation of very fine material (i.e. particle diameters between 10µm and 200µm) such as cement and fly-ash are more suited to, and is more efficient, if transported via fluidisation and/or pneumatic methods (Siperm, 2020).
  - The transportation of material in the normal range (from 200 µm to visible lumps) is more suited to transportation via typical methods such as belt conveyors or continuous unloaders.
  - The transportation of material in the coarse to very coarse range is more suited to handling by bucketwheel or grab unloading/loading methods.
- Stowage factor and angle of repose (the steepest angle at which a sloping surface formed of loose material is stable);
- Flow characteristics:
  - Free flowing or non-free flowing;
  - Static angle of repose (determines storage area);
  - Dynamic angle of repose (determines maximum conveyor inclination);
  - Cohesion and adhesion characteristics;
  - Wall friction characteristics;
  - Tendency of the commodity to bridge or cake (i.e. when the commodity forms lumps which interrupts its flow, as is common in the fertilizer industry); and
  - Need for mechanical assistance.
- Dustiness and the impact of moisture on the proposed commodities.
  - Dust control is a major consideration for handling of dry products. For transfer points, this is often controlled by dust extraction through filter cloth using fans or by suppressing airborne dust with fine droplets of water with special agents. For open stockpiles, this is often controlled using water sprays or by creating a membrane on the stockpile using an additive such as glucose. Key characteristics for evaluation of material dustiness include particle size and shape, specific weight and moisture content.

- Moisture content will affect handling, flow, weight, stability, dustiness and bacteria/fungal growth of dry bulk materials.

2.6.10 Stockyard conceptual design and stockyard handling considerations

According to Ligteringen and Velsink (2012), the following variables are essential for the sizing of the area required for the stockpile:

- The height and proposed shape of stockpiles;
- The size of incoming/outgoing vessels and the distribution of vessel sizes;
- The size of incoming/outgoing landside transport modalities and their distributions; and
- The ship loading and unloading rates.

Further, the strategic reserves that are required to be maintained (calculated as a proportion or percentage of the overall yearly throughput handled), the storage type (open storage versus closed storage) and the storage configuration (number of stockpiles, number of stockpile lanes etc) should also be considered.

The initial length of the stockpiles should also be considered, and according to Ligteringen and Velsink (2012), a first order estimate of the total width and length required for stockpiles may be made using the equation shown in Equation 2-5.

Equation 2-5: First order estimate of stockpile length and width (Ligteringen and Velsink, 2012)

$$V = \frac{b \times h \times l}{2} \times m_b$$

Where:

- V is equal to the maximum volume of cargo in storage;
- b is equal to the width of the stockpile;
- h is equal to the height of the stockpile;
- l is equal to the length of the stockpile; and
- m_b is equal to the utilization ratio.

Further to the above, stockyard handling considerations (based on observations of operating terminals such as Richards Bay Coal Terminal and Nacala-a-Velha Coal Terminal) may vary between terminals due to the size of the stockyard and the throughput capacity. This impacts the number and capacity of stockyard handling equipment and also impacts the stockyard handling equipment configuration (i.e. the number of stockyard handlers per stockyard lane)

2.7 Theoretical terminal design approach

2.7.1 General

Currently, the most widely accepted design approach for dry bulk terminals is based on the design approach introduced by the United Nations Conference on Trade and Development in 1985 (UNCTAD, 1985). However, when assessing this method it can be seen that it is not very specific, as it does not specify a number of key input parameters, such as the required quay length, the required stockyard size and its configuration. However, given that the UNCTAD method is almost 35 years old, certain assumptions are dated, as detailed by Van Vianen (2015) as:

- The assumption that that ship(un)loaders cannot operate at multiple berths leading to an over-dimensioning of the number of loaders and the required berth lengths; and
- The assumption that the unloading capacity remains constant during the unloading of the entire ship.

Studies, such as those by Ligteringen and Velsink (2012), introduced some general rules-of-thumb values for some dry bulk terminal characteristics and provided an overview of the requirements for handling equipment at dry bulk terminals.

In addition, daily occurrences at an operating terminal such as the arrival times and patterns of vessels, the arrival times and patterns of hinterland transportation and the loading and unloading of the stockpiles are typically stochastic processes, and thus their variability impacts the design outputs. The impact of these stochastic processes should be considered in the detailed design stages of a dry bulk terminal in order to realize optimised designs. However, a higher level, deterministic driven approach to the design may be more suited to the initial stages of scoping and project feasibility stages.

2.7.2 Terminal design approach

As is the case of typical large scale infrastructure projects, the design process usually consists of three major steps:

- Project scoping, feasibility and conceptual design;
- Basic or preliminary design; and
- Detailed design

Given that the initial phase (i.e. the feasibility and conceptual design phase) is vitally important in the final design and layout, it is critical that this phase is based on the correct information to provide the client/project promoter with a relatively good idea of the funding requirements, the capacity and capability of the terminal and the critical constraints that may need to be considered during project development.

These may include, according to Kleinheerenbrink (2012):

- The envisaged type of terminal (import or export);
- The optimum/desired annual export/import tonnage throughput;
- Characteristics of the predominant cargo/cargoes;
- The number of working days per year;
- The number of port calls per year and average vessel size;
- The average wagon, barge or truck loading rate; and
- The physically available storage capacity.

In practice, during the conceptual design phase for a greenfield port terminal, a selection of sites may already have been shortlisted. Therefore, the available area limits which define the size of the terminal and maximum storage area may already be available. Depending on the ownership model of the port terminal (customer-oriented versus owner-oriented), the throughput capacity and the time that the commodity spends may also be impacted. Other limitations or requirements specified by the client, international standards and regulations by the government may also be present.

2.7.3 Landside / storage capacity design approach

The landside terminal connects the seaside and the hinterland side and primarily consists of a stockyard. The stockyard is the buffer between the demand side and the supply side (Van Vianen *et al.*, 2011). For example, in the case of an import terminal, the demand side is the landside, and the supply side is the seaside, with the stockyard being a buffer where material supply is stored prior to its departure to customers hinterland.

The design of the size and configuration of the stockyard is crucial given its location and importance in the supply chain. If the stockyard is sized incorrectly and is too small, bottlenecks will form on the supply size (ships or hinterland transport modes will queue for disproportionate amount of time). If the stockyard is sized incorrectly and is large, the port developers would have invested a disproportionate amount of money in land acquisition and other aspects such as the design and construction of engineering services, and thus may struggle to recoup their investments efficiently.

2.8 Appraisal of previously developed design approaches for dry bulk terminal

2.8.1 General

A number of authors have presented varying computational approaches and methodologies for the design of a dry bulk terminal or some specific infrastructure elements of a dry bulk terminal. These include, *inter alia*:

- Van Vianen (2015), who proposed and developed a simulation driven computer model for the end-to-end design of a dry bulk terminal;
- Kleinheerenbrink (2012), who proposed and developed a computational tool that for the conceptual design of a dry bulk terminal; and
- Bot (2012), who proposed and developed a simulation-driven computer model for determining only the storage area of an import dry bulk terminal.

Each of the above studies will be reviewed in terms of the approach and methodology employed and the key findings. The implications of the key findings and the approaches employed by the authors of the three aforementioned studies on the development of the new conceptual design tool will also be discussed.

It should be noted that of the aforementioned studies, two studies (i.e. Van Vianen (2015) and Bot (2012)) proposed approaches that incorporated computational simulation using simulation-related computer software, which is beyond the scope of this Thesis. However, for the sake of completeness, the three studies listed above (i.e. Van Vianen (2015), Kleinheerenbrink (2012) and Bot (2012)) are discussed in the text below. Further, it should be noted that the computational models developed during the three aforementioned studies were not made available and hence these models hence have not been reviewed as part of this Thesis. The below review is based on an appraisal of each of the aforementioned authors' written masters (i.e. Kleinheerenbrink (2012) and Bot (2012)) and doctoral (i.e. Van Vianen (2015)) theses.

2.8.2 Van Vianen (2015)

Van Vianen (2015) stated that due to the fact that each element or subsystem of a dry bulk terminal is inter-dependant, for the modelling of dry bulk terminal to be effective, the approach must assess each of the subsystems individually and thereafter merge these into a single end-to-end terminal model. Each subsystem is analysed individually and then modelled using dedicated subsystem simulation models to account for stochastic variations that occur in reality.

According to Van Vianen (2015), these dedicated subsystem simulation models were developed using Delphi ®, which is a proprietary programming language and software development kit that uses the Pascal programming language and is developed and maintained by Embarcadero Technologies (Penland, 2020). Van Vianen (2015) further stated that the application of his simulation models developed using Delphi ® was undertaken in TOMAS, which is a process orientated simulation tool based on Delphi ® inputs (TOMASWeb, n.d.). The simulation driven approach for Van Vianen's (2015) study included, *inter alia*, the following subsystems of a dry bulk terminal:

- Seaside and quay layout design, which included *inter alia*:
  - The development of a dedicated seaside simulation model that included stochastic ship arrival processes and stochastic ship service time distributions;

  - The determination of the number of berths and the number and characteristics of the quay cranes required using the dedicated seaside simulation model;
  - The determination of the quay layout (either single berth quay or multi-berth quay) using the dedicated seaside simulation model; and
  - A case study whereby Van Vianen's (2015) dedicated seaside simulation model was used to evaluate a proposed new quay layout due to an increase in annual throughput for an import dry bulk terminal.
- Landside operation and machine specification, which included *inter alia*:
  - The development of a dedicated landside simulation model that included the stochastic arrivals of hinterland-bound transport modes and stochastic variations in the interarrival times and service times of hinterland-bound transport modes;
  - A case study whereby Van Vianen's (2015) dedicated landside simulation model was used to select railcar unloading machines at an export dry bulk terminal.
- Stockyard sizing, which included *inter alia*:
  - A simulation model developed by Van Vianen (2015) to determine the stockyard size required which included stochastic variations in ship sizes bulk material storage times and ship interarrival times;
  - A case study whereby Van Vianen's (2015) dedicated stockyard sizing simulation model was used to determine the required stockyard area for a specific import terminal.
- Stockyard machine selection, which included *inter alia*:
  - A simulation model developed by Van Vianen (2015) to select various stockyard machine capacities so as to adequately service the demands of both the seaside and landside elements.

Van Vianen (2015) developed an approach whereby the dry bulk terminal is subdivided into its individual subsystems, applied a simulation model for each subsystem and ultimately merged these individual subsystem simulation models to generate an end-to-end simulation integrated dry bulk terminal design method. Van Vianen (2015) incorporated four major dry bulk terminal subsystems in this end-to-end simulation integrated dry bulk terminal design method developed using Delphi ® and executed in TOMAS. These are: the seaside, quay layout and quay crane subsystem; the landside and landside machinery subsystem; the stockyard sizing subsystem; and the stockyard machinery subsystem.

Given that Van Vianen (2015) employed a simulation driven approach for the design of a dry bulk terminal, only the four subsystems proposed by Van Vianen (2015) will be employed as the basis for the development of the new conceptual design tool. This simulation driven approach has its merits, as it accounts for stochastic effects and allows for the design parameters of the entire terminal (when each of the subsystems are merged) to be interlinked, as is the case in reality. However, the new conceptual design tool is not aimed at being a simulation driven tool and as outlined in Section 2.6.2, the new conceptual design tool should incorporate a factor to account for 'peaks' that occur as a result of stochastic effects.

2.8.3 Kleinheerenbrink (2012)

Kleinheerenbrink (2012) proposed and developed a design support computer-based model to support the conceptual design process of a dry bulk terminal and concluded that the model provides outputs in respect of the required equipment and storage facilities based on user inputs.

Kleinheerenbrink (2012) developed his computer-based model in Microsoft Excel and to a large extent, the model is based on the four dry bulk terminal subsystems also proposed by Van Vianen (2015). The model developed by Kleinheerenbrink (2012) is capable of several output parameters including the required quay length, the number of berths, the number of vessel and landside loading and unloading equipment and the number and capacities of stockyard equipment. Kleinheerenbrink's (2012) computer-based model comprises two distinct parts, namely a terminal design part and a storage capacity determination part.

The terminal design part determines the required amounts and capacities of handling equipment for the four dry bulk terminal subsystems (i.e. seaside handling, landside handling, stockyard handling and stockyard storage). Kleinheerenbrink's (2012) storage capacity determination part is based on a simulation-driven approach whereby the material arrival and departure rates into and out of the stockyard are modelled, and the storage capacity is determined by comparing an allowed or desired waiting time of vessels. Kleinheerenbrink's (2012) computer-based model incorporates the use of limitations based on empirical values and capacity ratios, which are specified by the user. These limitations then provide the boundaries within which the model's outputs are confined.

It is noted that Kleinheerenbrink's (2012) computer-based model was not made available for review and hence the mechanics of the model cannot be appraised. The overview of the methodology of Kleinheerenbrink's (2012) study provided hereunder is solely based on that author's written work (i.e. Kleinheerenbrink, 2012):

- The terminal design part of the Kleinheerenbrink's (2012) computer-based model:
  - The terminal design part of the Kleinheerenbrink's (2012) computer-based model broadly focuses on providing an output for the seaside and landside aspects (including the number of vessel or hinterland transport loading/unloading equipment respectively and the stockyard aspect (including the number of lanes and the capacity of stockyard equipment).
  - Kleinheerenbrink's (2012) computer-based model's seaside component requires the user of the model to specify the annual throughput, the type of terminal, the average vessel size and the limit of the maximum number of loaders/unloaders per vessel. The seaside component of Kleinheerenbrink's (2012) computer-based model then generates, based on the specified inputs and limitations, the resultant quay length and the handling capacity of the vessel loaders/unloaders.
  - Kleinheerenbrink's (2012) computer-based model's landside component requires the user of the model to specify the capacity of the landside handler, the capacity of the landside transport mode and the threshold of the handler utilization. The landside component of Kleinheerenbrink's (2012) computer-based model then generates, based on the specified inputs and limitations, the resultant number and handling capacity of the landside loaders/unloaders.
  - Kleinheerenbrink's (2012) computer-based model's stockyard component requires the user of the model to specify the desired storage capacity, and the limitations in terms of the dimensions of the stockpiles (height and width). The stockyard component of Kleinheerenbrink's (2012) computer-based model then generates, based on the specified inputs and limitations, the resultant number and handling capacity of the stockyard loaders/unloaders as well as the number of stockyard lanes and the associated stockyard capacity.
- The storage capacity part of the Kleinheerenbrink's (2012) computer-based model:
  - The storage capacity part of the Kleinheerenbrink's (2012) computer-based model broadly focuses on the determination of the of the required storage capacity based on the outputs as generated by the terminal design part of the computer-based model (Kleinheerenbrink, 2012).
  - The storage capacity part of the Kleinheerenbrink's (2012) computer-based model then simulates the various processes from arrival of material at the terminal to the departure of that material from the terminal, such as the arrival rate of vessels, the handling rate of the seaside handlers, the handling rate of the landside handlers and handling rate of the stockyard handlers are then simulated (Kleinheerenbrink, 2012).
  - Ultimately, the storage capacity part of the Kleinheerenbrink's (2012) computer-based model determines the required storage capacity of a terminal based on specified maximum vessel waiting time.

To a large extent, Kleinheerenbrink's (2012) computer-based model is based on the design guidelines outlined in UNCTAD (1985) and in some cases, several of the findings of Van Vianen *et al.* (2011) have also been referenced. Kleinheerenbrink's (2012) work provides a framework for the development of the new conceptual design tool, but is aimed at providing the user with a particular output which is contrasted with the aim of the new conceptual design tool is to provide a wide-range or feasible outputs (or Concept Options) as well as illustrate to the user of the model the limits specified for each of the desired output parameters

2.8.4 Bot (2012)

Bot (2012) proposed and developed a simulation driven method, also developed in Delphi ® and executed in TOMAS that allows for the determination of the required storage capacity of an import dry bulk terminal. Bot (2012) stated that in order to minimize the payment of any or all demurrage costs, all ships arriving are required to be services within that dry bulk terminal's pre-arranged time and hence in the instance of an import terminal, the stockyard needs to be sufficiently large to eliminate a bottleneck occurring.

In order to size the stockyard of an import terminal adequately, Bot (2012) developed a simulation model in Delphi ® which included stochastic occurrences such as the varied inter-arrival times of ships, varied vessel mixes and vessel capacities, and the varied material storage times within the stockyard. Further, in order to optimize the sizing of the import terminal stockyard, Bot (2012) incorporated the use of Net Present Value (NPV) into his simulation model by including development costs and anticipated terminal revenues. The simulation model developed by Bot (2012) to determine the storage capacity of an import dry bulk terminal is based on a deterministic portion and a stochastic portion. According to Bot (2012), the deterministic portion of the storage capacity may be calculated by the multiplication of the annual throughput with the average time that the material may spend in storage while the stochastic portion is dependent on the stochastic effects and can be expressed (through the simulation) as a function of the annual throughput.

Bot (2012) concluded that the largest effects on the required storage capacity of an import dry bulk terminal are annual throughput and the storage time in the stockyard. In addition to these two factors, Bot (2012) concluded that the inter-arrival distribution times of vessels and the variance in vessel characteristics also impacted the stochastic portion of the storage capacity. Bot (2012), in a similar fashion to Van Vianen (2015), employed a simulation driven approach for the design of an element of a dry bulk terminal. As outlined in Section 2.6.2, the storage capacity of the stockyard varies with the annual throughput capacity and as such, the new conceptual design tool should incorporate Bot's (2012) findings by adding a 'peak' factor to certain parameters to account for stochastic effects. It is noted that in reality, for detailed design phases, this peak factor will likely be replaced following a simulation-driven detailed design process.

2.9 Selected existing dry bulk terminals and properties

The present section aims to explore a selected number of iron ore and coal dry bulk terminals globally, outlining the salient features in Table 2-7. A number of large and renowned terminals around the world were not selected (especially in the People's Republic of China, South Korea and Japan) as information relating to those terminals is often not readily available. In summary, the following 13 terminals were selected, and from these terminals, seven have been selected as comparative case studies, detailed in Section 5.

Africa:

- Richards Bay Coal Terminal (RBCT), South Africa;
- Iron ore export terminal at the Port of Saldanha, South Africa; and
- Export coal terminal at the Port of Nacala, Mozambique.

Australasia;

- Four export iron ore terminals at Port Hedland, Australia; and
- Carrington Coal Terminal at the Port of Newcastle, Australia.
- Kooragang Coal Terminal at the Port of Newcastle, Australia

South America

- Export iron ore terminal at Ponta da Madeira, Brazil.

North America

- Export coal terminal at the Port of Ridley, Canada.

Europe

- Import coal and iron ore terminal at the Port of Rotterdam, Netherlands; and
- Import coal terminal at the Port of Hamburg, Germany.

A consolidated version of Table 2-7 can be found in Appendix B.

Table 2-7: Properties of selected dry bulk terminals globally

<table>
<tr><th>#</th><th>Port/Terminal Name</th><th>Details</th></tr>
<tr><td>1</td><td>Richards Bay Coal Terminal at the Port of Richards Bay, South Africa</td><td>
Description:

The Richards Bay Coal Terminal (RBCT) is a coal export terminal situated in the Port of Richards Bay, South Africa.
The terminal opened in 1976 with an original capacity of 12 million tonnes per annum which has since grown to an annual capacity of 91 million tonnes per annum (Richards Bay Coal Terminal, 2014).
The RBCT quay 2,2 kilometres long with six berths and four ship loaders and the terminal has a stockyard capacity of 8,2 million tonnes (Richards Bay Coal Terminal, 2014).
Coal is transported to the terminal by rail and railway wagons are offloaded by means of several mechanical tandem rail tipplers. A conveyor system transports coal to the stockpile areas, or in some instances via a direct conveyor line, to a ship loader that offloads directly to a waiting vessel.

Details: (Source: Richards Bay Coal Terminal, 2014)
<table>
<tr><th>Item</th><th>Value</th></tr>
<tr><td>Terminal type</td><td>Export</td></tr>
<tr><td>Primary commodity</td><td>Coal</td></tr>
<tr><td>Quay Length</td><td>2,200m</td></tr>
<tr><td>Berths</td><td>Six</td></tr>
<tr><td>Ship loaders and ship loading capacity</td><td>Four shiploaders, with the following capacities:

Shiploaders 1 and 2 have a maximum flow rate of 8 500 tonnes per hour.
Shiploader 3 is capable of 10 000 tonnes per hour; and
</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>#</th><th>Port/Terminal Name</th><th>Details</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td></td><td>Shiploader 4, being the largest, is capable of loading a ship at 11 000 tonnes per hour</td></tr>
<tr><td>Throughput capacity</td><td>91 million tonnes per annum</td></tr>
<tr><td>Stockyard capacity</td><td>8.2 million tonnes</td></tr>
<tr><td>Terminal equipment</td><td>7 stacker-reclaimers, 2 stackers and 1 reclaimer at a capacity of 4,300t/h</td></tr>
</table>
</td></tr>
<tr><td>2</td><td>Iron ore terminal at the Port of Saldanha, South Africa</td><td>
Description:

The port at Saldanha Bay is the only dedicated iron ore export facility in South Africa and is larger than the country’s other four major ports combined. The port was originally constructed during the early 1970’s to facilitate the export of iron ore and bulk crude oil.
The iron ore terminal’s current capacity of 60MTPAis forecasted to start ramping up from 2022 to a final total capacity of 90MTPA by 2025 (Transnet Port Terminals, 2013).
Port facilities consist of a 990m long jetty with two iron ore berths and one crude oil berth joined to the north shore of the harbour by a 3100m causeway (Transnet Port Terminals, 2013).
The ore quay at Saldanha has two berths where two vessels of 310,000 deadweight tonnage can simultaneously tie up at the iron ore jetty (Transnet Port Terminals, 2013).

Details: (Source: Transnet Port Terminals, 2013)
<table>
<tr><th>Item</th><th>Value</th></tr>
<tr><td>Terminal type</td><td>Export</td></tr>
<tr><td>Primary commodity</td><td>Iron ore</td></tr>
<tr><td>Quay Length</td><td>630m</td></tr>
<tr><td>Berths</td><td>Two</td></tr>
<tr><td>Ship loaders and shiploading capacity</td><td>Two shiploaders at 8,000 t/h</td></tr>
<tr><td>Throughput capacity</td><td>60 million tonnes per annum</td></tr>
<tr><td>Stockyard capacity</td><td>12,4 hectares at 5.1 million tonnes</td></tr>
<tr><td>Terminal equipment</td><td>4 x 8000 t/h stacker-reclaimers;</td></tr>
</table>
</td></tr>
<tr><td>3</td><td>Coal terminal at the Port of Nacala, Mozambique</td><td>
Description:

Nacala’s natural deep-water harbour and state-of-the-art facilities offer significant advantages over the Mozambican port of Beira which requires regular dredging (Global Energy Monitor, 2019).
Nacala coal terminal has the capacity to handle 18 million tonnes per annum (Synergia Consulting, 2016).
Vale (world renowned mining entity) funded the development of the port and associated railway line and state that the natural characteristics of the port enable operations at any time of the day (Vale, 2017).

Details: (Source: Synergia Consulting, 2016)
<table>
<tr><th>Item</th><th>Value</th></tr>
<tr><td>Terminal type</td><td>Export</td></tr>
<tr><td>Primary commodity</td><td>Coal</td></tr>
</table>
</td></tr>
</table>

#	Port/Terminal Name	Details	
		Quay Length	385m
		Berths	1
		Ship loaders and shiploading capacity	2 ship loaders at 5,100t/h
		Throughput capacity	18 million tonnes
		Stockyard capacity	1 million tonnes.
		Terminal equipment	• 1 rotary car dumper at 4,800t/h; • 2 forklift trucks at 4,800t/h; and • 2 reclaimers at 5,100t/h
4	**Iron ore terminals at the Port Hedland, Australia**	**Description:** • Port Hedland is a large volume, bulk mineral export port located on Australia's north west coast in the resource rich Pilbara region (Pilbara Ports Authority, 2020). • Iron ore is overwhelmingly the main cargo handled at the port. • The port layout is distinctly divided into four terminal areas (Pilbara Ports Authority, 2020): – Finucane Island with BHP providing 4 iron ore berths; – Nelson Point with BHP providing 4 iron ore berths; – Anderson Point with Fortescue Metals Group (FMG) providing 5 iron ore berths; and – Stanley Point with Royal Hill Infrastructure (RHI) providing 2 iron ore berths. **Details: (Source: Pilbara Ports Authority, 2020)**	
		Item	**Value**
		Terminal type	Export
		Primary commodity	Iron Ore
		Quay Length	• Finucane Island: – Berths A and B = 838m; – Berths C and D = 680m; • Nelson Point: – Berths A and B = 660m; – Berths C and D = 838m; • Anderson Island: – Berths 1, 2 and 3= 1,190m; – Berths 4 and 5 = 1,190m; • Stanley Point; – Berths 1 and 2 = 730m
		Berths	15 iron ore berths in total
		Ship loaders and shiploading capacity	• 3 shiploaders at Finucane Island at 12,500t/h; • 4 shiploaders at Nelson Point at 12,500t/h; • 3 shiploaders at Anderson Island at 13,500t/h;

#	Port/Terminal Name	Details	
			• 1 shiploader at Stanley Point at 12,700t/h.
		Throughput capacity	• Finucane Island – 240MTPA: • Nelson Point – 268MTPA: • Anderson Island – 180MTPA: • Stanley Point – 60MTPA;
		Stockyard capacity	• Finucane Island – undisclosed; • Nelson Point – undisclosed; • Anderson Island – undisclosed; • Stanley Point – 2.3 million tonnes;
		Terminal equipment	• Finucane Island – undisclosed; • Nelson Point – undisclosed; • Anderson Island – undisclosed; • Stanley Point: – 11,250tph rotary car dumper system, which tips two ore cars at a time; – Four conveyors; – Two 14,500tph rail mounted stacker; – One 16,720tph rail mounted reclaimer.
5	**Carrington Coal Terminal at the port of Newcastle, Australia**	**Description:** • The Carrington Coal Terminal in Australia is operated by Port Waratah Coal Services Limited (PWCS) and has a licenced capacity of 25 million tonnes of coal per annum (Port Waratah Coal Services, 2020). • The majority of coal is delivered by rail through two rail receival facilities and vessels arriving at Carrington Coal Terminal are loaded utilising two shiploaders (Port Waratah Coal Services, 2020). **Details: (Source: Port Waratah Coal Services, 2020)**	
		Item	**Value**
		Terminal type	Export
		Primary commodity	Coal
		Quay Length	615m
		Berths	2
		Ship loaders and shiploading capacity	2 ship loaders at 2,500t/h
		Throughput capacity	25 million tonnes per hour
		Stockyard capacity	750,000 tonnes
		Terminal equipment	• 2 rail unloaders at 4500t/h • 4 stacker-reclaimers at 2,500t/

#	Port/Terminal Name	Details
6	**Kooragang Coal Terminal at the Port of Newcastle, Australia**	**Description:** • The Kooragang Coal Terminal in Australia is operated by Port Waratah Coal Services Limited (PWCS) and has a licenced capacity of 120 million tonnes of coal per annum (Port Waratah Coal Services, 2020). • All of the coal received at Kooragang Coal Terminal is delivered by rail into four rail receival facilities located on the northern edge of the terminal. • Coal is stacked into length stockpiles and is then loaded onto vessels for the export market via five berths that are able to accommodate vessels with a draught of up to 16.5m (Port Waratah Coal Services, 2020). **Details: (Source: Port Waratah Coal Services, 2020)**

Item	Value
Terminal type	Export
Primary commodity	Coal
Quay Length	1396m
Berths	5
Ship loaders and shiploading capacity	3 ship loaders at 10,500t/h
Throughput capacity	25 million tonnes per hour
Stockyard capacity	4.2 million tonnes
Terminal equipment	• 4 rail unloaders at 8.500t/h • 6 stacker-reclaimers at 8,500t/

#	Port/Terminal Name	Details
7	**Ponta da Madeira, Brazil**	**Description:** • Ponta da Madeira is a large iron ore loading port in Sao Luis, in the Northern part of Brazil. • This terminal is capable of accommodating five ships at the same time. It is mainly used to export iron ore (Wilson Sons, 2020). • The terminal has two distinct stockyards, one with a (measured) length of circa 1,500m and the other with a (measured) length of circa 830m **Details: (Vale, 2015)**

Item	Value
Terminal type	Export
Primary commodity	Iron ore
Quay Length	1,915m
Berths	5
Ship loaders and shiploading capacity	8 ship loaders at 8,000t/h
Throughput capacity	190 million tonnes per annum
Stockyard capacity	14 million tonnes
Terminal equipment	19 stacker reclaimers operating at an undisclosed capacity

#	Port/Terminal Name	Details
8	**Ridley Coal Terminal, Canada**	**Description:** • This shipping terminal on Ridley Island in northern British Columbia has a handling capacity of 18.5 MPTA of coal (Ridley Terminals Inc, 2020); • The terminal has the ability to load vessels at rates of up to 9,000 tonnes per hour, unload railcars at rates up to 6,000 tonnes per hour and has an overall annual shipping capacity of 16 million tonnes (Ridley Terminals Inc, 2020).

Details: (Source: Ridley Terminals Inc, 2020)

Item	Value
Terminal type	Export
Primary commodity	Coal
Quay Length	320m
Berths	2 berths
Ship loaders and shiploading capacity	2 shiploaders at 4,500t/h
Throughput capacity	18.5 million tonnes per annum
Stockyard capacity	1.4 million tonnes
Terminal equipment	2 stacker reclaimers at 6000t/h Train unloading at 6,000t/h

#	Port/Terminal Name	Details
9	**EMO coal terminal, Port of Rotterdam, Netherlands**	**Description:** • EMO coal terminal is one of the largest dry bulk terminals in Europe and is strategically located in the Port of Rotterdam. Rotterdam is situated at the mouth of the rivers Rhine and Maas and inland shipping is therefore an ideal mode of transport for the reliable and cost-effective movement of large volumes to countries like Germany, France and Belgium (HES International, 2020). • EMO has a storage capacity of 7 million tonnes and has 4 deep-sea berths with a maximum draft of 23 m (HES International, 2020).

Details: (Source: Dry Cargo International, 2011)

Item	Value
Terminal type	Import
Primary commodity	Coal
Quay Length	1,365m
Berths	4 berths
Ship loaders and shiploading capacity	4 ship loaders at 3,300t/h
Throughput capacity	60 million tonnes per annum
Stockyard capacity	7 million tonnes
Terminal equipment	• 6 landside handlers at 3,800t/h • 6 Stacker reclaimers at 6000t/h

<table>
<tr><th>#</th><th>Port/Terminal Name</th><th>Details</th></tr>
<tr><td>10</td><td>Port of Hamburg (Hansaport), Germany</td><td>Description:
• More than 18 million tonnes of coal and ore are imported annually via Port of Hamburg, with the bulk of this going through Hansaport – Germany's largest seaport terminal for dry bulk cargoes;
• Hansaport terminal has 4 ship loaders/unloaders, and 5 stacker reclaimers, with a mixed use stockyard comprising of both coal and iron ore commodities (Port of Hamburg, 2020).

Details: (Source: Port of Hamburg, 2020)
<table>
<tr><th>Item</th><th>Value</th></tr>
<tr><td>Terminal type</td><td>Import</td></tr>
<tr><td>Primary commodity</td><td>Coal and Iron Ore</td></tr>
<tr><td>Quay Length</td><td>760 m quay for sea-going-vessels, with a max. draft of 15.1m</td></tr>
<tr><td>Berths</td><td>4 berths</td></tr>
<tr><td>Ship loaders and shiploading capacity</td><td>4 ship loaders/unloaders at 1,200t/h</td></tr>
<tr><td>Throughput capacity</td><td>18 million tonnes per annum of coal an iron ore</td></tr>
<tr><td>Stockyard capacity</td><td>3 million tonnes / 350,000m^2</td></tr>
<tr><td>Terminal equipment</td><td>5 stacker-reclaimers at an undisclosed capacity.</td></tr>
</table></td></tr>
</table>

(Sources: Dry Cargo International, 2018; Global Energy Monitor, 2019; Pilbara Ports Authority, 2020; Port of Hamburg, 2020; Port Waratah Coal Services, 2020; Richards Bay Coal Terminal, 2014; Ridley Terminals Inc, 2020; Synergia Consulting, 2016; Transnet Port Terminals, 2013; Vale, 2015; Wilson Sons, 2020)

2.10 Impact of the conceptual design variables considered on the development of the new conceptual design tool

In addition to the impact of the studies previously conducted by others on the development of the new conceptual design tool as outlined in Section 2.8, for the purposes of this Thesis, the impact of the conceptual design variables considered from the literature review may be summarized as follows:

- **Stochastic effects:**
  - A conservative flexibility factor (as opposed to a peak factor) of 10% should be added to both minimum and maximum limits for output parameters to extend the typical design limitations gleaned from literature and to allow for (conceptual) designers to obtain a wider range of options to take forward into detailed design stages.

- **Terminal type and operating mode:**
  - Only import and export terminals may be considered for incorporation into the new conceptual design tool; and
  - Only single product terminals may be considered (although various grades of ore should be catered for in the new conceptual design tool). Given this restriction, the new conceptual design tool will not cater for the calculation of blending areas or for the configuration of (typically circular) blending stockyards and associated specialized blending equipment.

- **Demand forecasts and terminal throughput capacity**
  - It should be assumed that the demand forecasts are understood by the design tool user and that the terminal is being (conceptually) designed for a fixed annual throughput capacity. However, the new conceptual design tool should allow for the annual throughput to be varied, at will, by the user, so as to allow the impact of variations in annual throughput on other parameters to be assessed.

- **Cargo handling considerations:**
  - The user should be able to set the maximum occupancy or utilization level for each of the berths, seaside handling equipment, landside handling equipment and stockyard handling equipment. The default values for each of these should be contained in the new conceptual design tool but should be able to be changed at will by users.

- **Waiting time versus Service time:**
  - The waiting time / service time ratio may be set at an initial default value of 30% as outlined in Section 2.6.7 but should be able to be changed by the user.

- **Vessel Sizes:**
  - The dead weight tonnage of vessels calling at the port, based on the input vessel mix should be taken into account as this impacts the average size of the call vessel and the average number of port calls (for a given throughput). This also impacts the sizing of the berths and the required number and capacity of landside handling equipment and stockyard handling equipment.

- **Commodity types and characteristics.**
  - Although several bulk material characteristics have been listed in the literature review, only the bulk density and the angle of repose should be included.

- **Stockyard conceptual design and stockyard handling considerations:**
  - The new conceptual design tool should provide minimum and maximum allowable stockpile lane widths, based on literature guidelines and account for the spatial requirements for stockyard handling equipment including the spatial requirements for stacker-reclaimers, horizontal transport systems, engineering services and internal roads;
  - The new conceptual design tool should allow for a specified stacker-reclaimer configuration to be inserted by the user, based on an allocation of one or more stacker-reclaimers per stockpile lane, or an allocation of one stacker reclaimer for every two stockpile lanes.
  - The stockyard configuration as proposed by the new conceptual design tool should be limited to the typical windrow arrangement (i.e. the arrangement of stockpile lanes parallel to each other) and hence the new conceptual design tool will not be capable of generating outputs in respect of storage requirements for commodities that may be required to be enclosed within warehouses.

2.11 Literature review summary

An extensive literature review was undertaken in order to gain a deeper understanding of dry bulk terminals.

This section outlines the varying types of required infrastructure, and terminal equipment and the variables that may need to be considered in respect of the conceptual design of a dry bulk terminal and the associated stockyard size and stockyard configuration. As the new conceptual design tool is required to be capable of providing output design parameters for a variety of terminal sizes, the focus of the literature study was to outline key variables and core process only, with secondary variables and processes, such as the design considerations for horizontal transport or the storage considerations for blending of commodities being disregarded.

This section also provided a review of previously developed simulation-integrated and conceptual design tools, with the key findings from those studies outlined and their impacts on the development of the new conceptual design tool discussed. Further, this section described the salient characteristics of a selected number of dry bulk terminals around the world so as to provide the basis of the case studies to be undertaken with the proposed conceptual design tool.

3 New conceptual design tool development overview

This section outlines the approach taken to develop the new conceptual design tool. This section lays out the general development approach in section 3.1 and describes the modular development approach in section 3.2. This section also discusses the functionality and advantages of the new conceptual design tool in section 3.3.

3.1 New conceptual design tool general development approach

In general, a new conceptual design tool has been developed for this Thesis by the Author with the aim to provide potential project developers and financiers with a rapid high-level estimate of a number of the fundamental parameters of a dry bulk terminal, for a particular commodity and commodity flow direction and a given annual throughput. Thus, the new conceptual design tool was developed in a manner so as to provide a wide range of Concept Options that may be rapidly generated (for any project) and reviewed by the user based on the user's project-specific constraints and desired inputs.

In this case (where a user has project-specific constraints and desired inputs), a Concept Option or Concept Options may be defined as a range of outputs from the model (when one of the model inputs is fixed) that fall within the limitations or boundary limits set by the model. For example, in the case of the iron ore terminal at the port of Saldanha, which is developed in a relatively sparsely populous area with minimal apparent space constraints, the need to fully optimise stockyard area for the given throughput capacity and desired storage capacity is relatively less than in the instance of the Port of Newcastle, Australia, or the Port of Rotterdam, Netherlands, both of which are almost within the bounds of densely populated and built-up cities. The new conceptual design tool provides a range of options for consideration in terms of the seaside (or wet) infrastructure aspects as specific projects may have varied arrival patterns for ships and hence, may require more (or less) berths.

Numerous Concept Options are possible per module. Each Concept Option may have several Sub-Concept Options, which are the range of individual viable outputs from the conceptual design tool. Further, given that typically during the conceptual design and feasibility stages of the project, project developers are yet to finalize their costing and funding structures, the various Sub-Concept Options (i.e. the individual outputs of the model) should allow for trade-off decisions to be made. For example, in the instance where a project may require three berths to accommodate a given throughput, and the user initially assumes that seaside handling configuration will be a single ship loader/unloader per berth, the model should provide a number of Concept Options that shows similar handling capacities for a lesser number of berths (i.e. 2 berths) but with one more one ship loaders/unloaders per berth, without breaching the model limits (such as specified maximum berth utilization and the specified maximum waiting time / service time ratio).

In summary, the new conceptual design tool has been developed with the following approach:

- The user is required to provide certain critical inputs, such as the annual throughput capacity and the desired storage capacity. (Note that each of the required inputs to be provided are discussed in the present section);
- The user is then required to set the input or output limits based on their project specificities or confirm that the default limits apply to their project. These limitations may include the maximum storage capacity as a percentage of the proposed throughput capacity, or the maximum number of berths based on the

desired maximum berth utilization percentage. Note that each of the limitations to be checked/confirmed are also discussed in the present section;

- The user may then, based on the inputs and limitations, assess a number of Concept Options that are essentially the outputs of the model. The Concept Options are also illustrated by means of graphs. Graphical illustration allows the user to tweak their inputs at will and assess the Concept Options as outputs almost instantaneously. Concept Options include varied numbers of berths, varied capacities of seaside, landside and inter-terminal equipment and varied configurations of the proposed stockyard.
- Finally, once the user has chosen a particular terminal layout and stockyard configuration, the model will illustrate the selected Concept Option in relation to the other generated Concept Options on a graph.

The above approach will be explained in terms of each of the key model modules below.

3.2 New conceptual design tool modular development approach

3.2.1 General

As described in Section 2, a dry bulk terminal has three distinct areas. These are:

- The intake area (typically the landside for an export terminal or the seaside for an import terminal);
- an outtake area (typically the seaside for an export terminal or the landside for an import terminal); and
- a storage and handling area, where material passes through, is stored or is blended prior to leaving the dry bulk terminal.

For this purpose, the new conceptual design tool has been developed by the Author in three distinct modules, namely:

- Module 1 – Seaside handling and configuration module;
- Module 2 – Landside handling and configuration module; and
- Module 3 – Stockyard configuration and stockyard handling sub-modules;

The development process for the new conceptual design tool including the key inputs (‘critical inputs’), required assumptions and the framework governing the generated output Concept Options, specific to each of the above modules will be explained further in this section.

3.2.2 Development process – Module 1

Module 1 of the new conceptual design tool is focused on the seaside infrastructure component of the dry bulk terminal. This module is aimed at providing a range of Concept Options for the layout of the seaside infrastructure in terms of the number of berths, the number, configuration and capacity of the vessel loaders/unloaders and the resultant berth utilization.

3.2.2.1 Module 1 - inputs

There are a number of key inputs for Module 1 of the new conceptual design tool which are listed and detailed hereunder in Table 3-1.

Table 3-1: Module 1 inputs

Input number	Module 1 inputs	Description
1	The type of terminal and	• The new conceptual design tool requires the user to select either one of four options, viz. an import coal terminal; an import iron ore terminal; an export coal terminal; or an export iron ore terminal.

Input number	Module 1 inputs	Description
	terminal commodity	• The new conceptual design tool is limited in the fact that it does not cater for a dual-purpose dry bulk terminal (i.e. a terminal with both import and export operations, which is unlikely to occur in reality). The new conceptual design tool also does not cater for the movement or storage of than more than one commodity.
2	The annual throughput capacity of the terminal	The annual throughput capacity is specified by the user in million tonnes per annum (MTPA).
3	The number of ship loaders/unloaders per berth	• The number of ship loaders/unloaders per berth may be termed as the shiploader configuration. An initial estimate of the shiploader configuration must be selected by the user, with the options being a shiploader configuration of 1 (i.e. one vessel handler per berth), 0.5 (i.e. one vessel handler for two berths) or 2 (i.e. two vessel handlers per berth). • It is noted that as outlined by UNCTAD (1985), the effectiveness of vessel handlers decreases as the number of vessel handlers per vessel increases. UNCTAD (1985) specifies that a berth configuration factor be incorporated as follows – A berth configuration factor of 1 in the instance that a berth has 1 handler; – A berth configuration factor of 1.75 in the instance that a berth has 2 handlers; – A berth configuration factor of 2.25 in the instance that a berth has 3 handlers; – A berth configuration factor of 2.60 in the instance that a berth has 4 handlers; – A berth configuration factor of 2.85 in the instance that a berth has 5 handlers; • The assumption has been made for the new conceptual design tool that the number of shiploaders per berth is equivalent to the number of shiploaders per vessel (i.e. no more than one vessel can occupy a berth).
4	The initial estimate of the rated capacity of each of the shiploaders	• The initial estimate of the rated capacity of each of the shiploaders is to be specified by the user; • The new conceptual design tool generalises in the fact that the all shiploaders are assumed to have the same capacity. This may be the case in many terminals across the world, but in some instances such as at Port Hedland or at the Port of Richards Bay, the rated capacity differs between shiploaders on different berths.
5	The maximum berth utilization of the number of berths	• The new conceptual design tool requires the user to set the maximum berth utilization rate • Thoresen (2003) indicated that for an average level of arrival control by a port's administration, berth utilization should typically be below 65% for a terminal with five or less berths. However, in some instances berth utilization may reach up to 70% in the case of a terminal with 6 or more berths and a much higher level of arrival control by the port's administration.
6	Maximum waiting time to service time (wt/st) ratio	• The new conceptual design tool requires the user to set the maximum limit of the wt/st ratio. • It is usually considered that waiting time should not be more than 50% of service time (Kleinheerenbrink, 2012) and according to UNCTAD (1985), the economic optimum of the wt/st ratio is generally between 30% and 40%.
7	Effective operational days per year and working hours per day	The new conceptual design tool assigns a default value of 365 operational days per year (as is often the case at dry bulk terminals, such as at Richards Bay Coal Terminal and at EMO Terminal), and 24 hours per day. These values may be adjusted based on the user's project specificities.
8	Vessel mix	• Each of the 6 major classes of vessels (i.e. from handysize to VLOC) are required to be assigned an approximate call percentage, to establish the vessel mix and allow for the 'average' vessel that will call at the terminal to be established.

Input number	Module 1 inputs	Description
		• The user is likely to either approximate these based on the location of the specific terminal and the proposed annual throughput capacity or insert the vessel mix based on the findings of a market study.

3.2.2.2 Module 1 – processes from inputs to generated outputs

Based on the aforementioned inputs into module 1 of the new conceptual design tool, a number of processes have been coded into the new conceptual design tool to generate the Concept Options and are briefly discussed hereunder:

- 1) The new conceptual design tool initially validates the inputs in the following manner, to eliminate obvious errors and extreme scenarios:
  - The vessel mix is validated by simply testing if the sum of the inserted percentages for each of the vessel classes does not exceed 100% and
  - The berth utilization is validated by simply testing that the desired maximum berth utilization does not exceed 100%;

- 2) Based on the inserted vessel mix and the specified average vessel size within each vessel class, the new conceptual design tool then calculates the average vessel dimensions based on Van Vianen (2015), as outlined in Section 2.6.8 and approximates the average vessel call size based on the weighted product of the specified vessel sizes and their respective percentage distributions;

- 3) The new conceptual design tool then proceeds to calculate an initial berth utilization based on the initial estimate of the number of berths and the initial estimate of the handling capacity of the vessel handlers. The berth utilization calculation incorporates the following:
  - A through ship efficiency factor of 0.5 for import terminals or 0.7 for export terminals, based on UNCTAD (1985);
  - A berth configuration factor ranging from 1 to 2.85, based on the specified number of vessel handlers per vessel as outlined in UNCTAD (1985) and explained in Section 3.2.2.1.

- 4) A number of Concept Options are then automatically generated in Microsoft Excel by initially fixing the number of berths and varying both the capacity of the vessel handlers and the vessel handler configuration. In this manner and based on the maximum number of berths specified by the author during the development of the new conceptual design tool (i.e. 8 berths), a total of 175 Concept Options may be generated, each with a unique berth configuration and a unique associated handling capacity (although it should be noted that not all Concept Options may be viable, as the Concept Options generated are subject to limitations imposed by the user).

- 5) The generated Concept Options are then illustrated on a graph, along with the specified maximum berth utilization, so as to illustrate to the user the various available berth configurations. The new conceptual design tool then proceeds to perform an automatic iterative calculation of the berth utilization. This is based on an increased (or decreased number of berths) to achieve a berth utilization that is closest to (but below) the user-specified maximum desired berth utilization.

- 6) A calculation of the waiting time / service time ratio for a series of berth numbers is then undertaken by the new conceptual design tool, based on UNCTAD (1985) and limited by the maximum user-specified wt/st ratio.

- 7) A second set of Concept Options are then automatically generated in Microsoft Excel by now fixing vessel handler configuration and varying both the capacity of the vessel handlers and the number of berths. In this manner and based on the maximum number of berths specified by the author during the development of the new conceptual design tool (i.e. 8 berths), a total of 280 Concept Options may be generated each with a unique number of berths and a unique associated handling capacity (although it should be noted that not all Concept Options may be viable, depending on the limitations imposed by the user).

- 8) Should the berth utilization limits not be breached, the user can then select from the graphs (or confirm that their initial selection was correct) their desired berthing configuration and the new conceptual design tool will then calculate the quay length based on calculated average vessel length on arrival (LOA), and a factor of 1.1 outlined by Ligteringen (1999) as follows:

$$\textbf{Quay length} = \mathbf{1.1} \times \boldsymbol{n_b} \times (\mathbf{LOA}_{\boldsymbol{average}} + \mathbf{15}) + \mathbf{15})$$

where n_b is equal to the number of berths and $\mathrm{LOA}_{average}$ is the average calculated vessel length

- 9) The quay length factor is then calculated by dividing the annual throughput by the previously calculated total quay length (Ligteringen and Velsink, 2012) and is checked against the upper and lower quay length factor limits derived by Van Vianen *et al.* (2011).

3.2.2.3 Module 1 – primary outputs

Following the aforementioned processes, the primary outputs of module 1 of the new conceptual design tool are

- A number of Concept Options that present possibilities in which the wet infrastructure may be configured including the number of berths, the berth utilization and the length of the quay.
- A number of Concept Options that present possibilities in which the seaside handling capacity may be configured including the number of ship loaders/unloaders per berth, the total number of ship loaders/unloaders and their individual rated capacities.

In summary, the primary outputs of module 1 of the new conceptual design tool primarily relate to the number of berths (and the associated quay length and berth utilization) and the vessel handling configuration. From the generated Concept Options, the user is then able to confirm if the specified input parameters require adjustment to align with the user-specified limitations, or if from the various Concept Options, a particular output may be selected. Following the selection of an output from the generated Concept Options, module 1 will then provide the:

- Number of berths, the associated quay length and quay length factor;
- The number of vessel handlers per berth and the total number of vessel handlers;
- The capacity per vessel handler and the total installed handling capacity of the terminal

- The resultant berth utilization and a validation indicating if maximum berth utilization has been breached.

3.2.3 Development process – Module 2

3.2.3.1 Module 2 - inputs

There are a number of key inputs for Module 1 of the new conceptual design tool which are listed and detailed hereunder in Table 3-2.

Table 3-2: Module 2 inputs

Input number	Module 2 inputs	Description
1	The average transport capacity of the hinterland transport mode (i.e. the carrying capacity of the railcar, truck or barge):	• The new conceptual design requires the user to specify the expected average net transport capacity of the hinterland transport mode. • The new conceptual design tool initially specifies a default value of 84 tonnes per hinterland transport mode unit.
2	The number of landside handlers per wagon (landside loaders in the case of an import terminal, or unloaders in the case of an export terminal)	• The number of landside handlers per wagon is specified in a manner that is similar to the number of vessel handlers per vessel (i.e. the value is 1 if there is a single landside handler per landside transport unit, or 2 if there is are two landside handlers per landside transport unit. • In likely that in the case of an export terminal, a wagon tippler or a wagon dumper is employed as the landside handler (as is the case at the Iron Ore Terminal at the Port of Saldanha). These tipplers or dumpers may function as tandem tipplers, where two railcar wagons are tipped simultaneously. The new conceptual design tool does not specify the type of landside handler or cater for the occurrence of tandem tipplers but limits the number of handlers per landside transport unit to initially ascertain the required number and capacity of landside handlers.
3	The initial estimate of the rated capacity of each of the landside handlers	• The initial estimate of the rated capacity of each of the landside handlers is to be specified by the user; • The new conceptual design tool generalises in the fact that the all landside handlers are assumed to have the same capacity.
5	The average efficiency of each loader/unloader	• The new conceptual design requires the user to specify the average efficiency of the hinterland transport mode, with the new conceptual design tool assigning a default efficiency value of 75%.
6	The minimum and the maximum occupancy (or utilization) of handlers	• The new conceptual design requires the user to specify the minimum and the maximum occupancy of the hinterland transport mode, with the new conceptual design tool assigning a default efficiency value of 30% and 85% respectively.

3.2.3.2 Module 2 – processes from inputs to generated outputs

Based on the aforementioned inputs into module 2 of the new conceptual design tool, a number of processes have been coded into the new conceptual design tool to generate the Concept Options and are briefly discussed hereunder:

- 1) The new conceptual design tool calculates the required minimum landside handling capacity per hour (based on throughput capacity) and the minimum number of landside transport units required to be loaded per hour (based on the specified tonnage capacity of each landside transport units) by respectively:

  - dividing the annual throughput by the number of operational hours in the year; and
  - dividing the resultant minimum landside handling capacity per hour by the specified tonnage capacity of each landside transport units.

- 2) The new conceptual design tool then proceeds to generate Concept Options by simulating the landside handler utilization for a range of handling capacities and for a range of handling units by:
  - calculating the number of days, in a year that the handlers will be occupied (handler utilization); and
  - calculating the variance in this handler utilization based on a varying number of handling units.

- 3) the resultant landside handler utilization is then illustrated on a graph, which includes the prespecified maximum and minimum landside handler utilization.

3.2.3.3 Module 2 – primary outputs

Following the aforementioned processes, the primary outputs of module 2 of the new conceptual design tool are

- A number of Concept Options that present possibilities in which the landside infrastructure may be configured including the number of landside handlers and the landside handler utilization; and
- A number of Concept Options that present the seaside handling capacity requirements including the number of landside handlers and their required capacities.

In summary, the primary outputs of module 2 of the new conceptual design tool primarily relate to the number of landside handlers and the associated landside handlers utilization. From the generated Concept Options, the user is then able to confirm if the specified input parameters require adjustment to align with the user-specified limitations, or if from the various Concept Options, a particular output may be selected. Following the selection of an output from the generated Concept Options, module 2 will then provide the:

- The required number of landside handlers;
- The capacity per landside handler and the total installed landside handling capacity of the terminal; and
- The resultant landside handler utilization and a validation indicating if maximum landside handler utilization has been breached.

3.2.4 Development process – Module 3

3.2.4.1 Module 3 – inputs

There are a number of key inputs for Module 1 of the new conceptual design tool which are listed and detailed hereunder in Table 3-3.

Table 3-3: Module 3 inputs

Input number	Module 3 inputs	Description
1	Percentage of throughput required in storage	• The user should specify the required storage capacity of the dry bulk terminal, expressed as a percentage of the annual throughput; • The findings of Van Vianen *et al.* (2011) provide guidance to the user by showing that the storage capacity of the terminals examined in that study vary between a minimum of 3% to a maximum of 10% of annual throughput

Input number	Module 3 inputs	Description
		(for export terminals) between a minimum of 5% to a maximum of 22% of annual throughput (for import terminals). • The new conceptual design tool further extends the aforementioned guides by a 'peak' factor' of 10%, as explained in Section 2.6.2
2	Maximum height of the stockpile	• In general, the height of a stockpile is dependent on the commodity that is being handled as different commodities have different angles of repose, and the width of the stockpile. The angle of repose is defined as the steepest angle at which a sloping surface formed of loose material is stable, and hence the angle of repose combined with the width of the stockpile determines the theoretical maximum height that may be reached. However, in many instances, stockpile lanes are wide enough such that the height of a stockpile is not limited by the angle of repose but is rather limited by the stacker-reclaimer itself. This is because the height of the discharge tip of the stacker-reclaimer relative to the stockyard floor (i.e. the maximum height) is dependent on the luffing angle and the length of the stacker-reclaimer's boom. • Kleinheerenbrink (2012), states that 90% of the stockyard machinery has a stockpile height limit of between 10m and 22.3m, with an average value of 15.2m
3	Initial estimate of stockpile lane width	• The user is required to specify the initial width of the stockpile lanes. • From the terminals examined in Section 2.9, the width of stockpile lanes varies from 40m to 70m. In some extreme cases, as outlined by Kleinheerenbrink (2012), lane widths may be as low as 20 and as high as 140m, depending on annual throughput capacity, time spent in storage and terminal location.
4	Initial estimate of distance between piles in the same stockpile lane	• The amount of piles on the stockyard has a noteworthy effect on the required lane length due to the required width between stockpiles. • According to Bot (2012), the number of individual stockpiles for a terminal stockyard may be linearly related to the annual throughput with an accuracy of up to 66%.The number of piles varies significantly between import and export terminals as import terminals have 3.59 stockpiles per million tonnes of annual throughput and export terminals have 0.75 stockpiles per million tonnes annual throughput. • The number of piles per lane can then be approximated by dividing the total number of piles found in a stockyard by the number of lanes.
5	Width between adjacent stockyard lanes for stockyard machinery and engineering services	• The distance between adjacent stockpile lanes should be sufficient enough to accommodate for the rail gauge upon which stockyard handling equipment moves as well as be large enough to allow for engineering services (e.g. utilities and telecommunications infrastructure) to be installed. • According to Schoonees *et al.* (2020), rail gauges for stockyard handling equipment vary between 10m and 30m for stackers, between 8m and 20m for reclaimers and between 6 and 20m for stacker-reclaimers. It should be noted that the new conceptual design tool limits the selection of stockyard handling equipment to stacker-reclaimers only. • Engineering services for dry bulk terminals typically comprise services for water and fire, power and stormwater (Aldous, 2020). Further, depending on the project-specificities and the desired maintenance approach, the required water, fire, stormwater and power supply conduits may vary in width from between 700mm to 2m each (Aldous, 2020).
6	Stockyard handling equipment configuration and stockyard handling equipment capacity	• The stacker-reclaimer configuration may be defined as the number of stacker-reclaimers per lane. This can either be one stacker reclaimer that is able to service two stockpile lanes on either side of it (which is common in smaller stockyards such as Carrington Coal Terminal) or each lane is allocated 1 or more stacker-reclaimers (which is common in much large stockyards such as the iron ore terminals at Ponta da Madeira in Brazil or the Port of Qinhuangdao in China;

Input number	Module 3 inputs	Description
		• According to Kleinheerenbrink (2012), the maximum stacking and reclaiming capacities available on the market at that time (i.e. in 2012) for iron ore was 10,000 t/h and 15,000 t/h respectively.

3.2.4.2 Module 3 – processes from inputs to generated outputs

Stockyard area and sizing

- Stockyard length:
  - Based on the commodity selected and that commodity's associated properties (including its angle of repose and bulk density), the new conceptual design tool mathematically calculates the maximum height of the stockpile for a given stockpile width based on the assumption that the cross section of the stockpile is an isosceles trapezoid.
  - The calculated height is validated against the prescribed maximum stockpile height, which is a user-specified input.
  - The width of the top of the trapezoidal cross sectional stockpile can then be estimated by calculating the base of the two 'triangular' ends of the trapezoid, and subtracting this from the width of the stockpile;
  - The area of the cross sectional trapezoid may then be estimated by multiplying the average of the width of the base and the width of top with the calculated height.
  - The volume of the material in storage (in m^3) may then be estimated by dividing the user-specified storage capacity (in tonnes) by the density of the commodity (in m^3/tonne). This volume may then be divided by the calculated cross sectional area and then subsequently by the number of stockpile lanes to obtain the stockyard lane length.
  - The number of individual stockpiles per lane (as outlined by Bot, 2012 and explained in Section 3.2.4.1) is then calculated with the additional distance between piles added to the previously calculated lane length to ultimately obtain the length of the stockyard.

- Stockyard width:
  - The width of the stockyard may be estimated by multiplying the user-specified lane width by the number of lanes, including the distance allowances for the stacker-reclaimer rail and the engineering services.
  - The length to width ratio of the stockyard is then calculated and validated against the length to width ratios outlined by Kleinheerenbrink (2012) which include:
    - For import terminals, the average length to width ratio noted by Kleinheerenbrink (2012) is 2.5, with the lower and upper limits being 1.2 and 4.6 respectively;
    - For export terminals, the average length to width ratio noted by Kleinheerenbrink (2012) is 2.6, with the lower and upper limits being 1.3 and 4.5 respectively.

- Stockyard area
  - The area of the stockyard may then be calculated by the multiplication of the stockyard width with the stockyard length.

- The area of the stockyard is then validated against the lower and upper limits of the area that may be derived from the storage factors (defined as the ratio of the annual throughput to the storage area) outlined from the findings of Van Vianen *et al*. (2011) which include:
  - For import coal terminals, the lower and upper limits of the storage factor ratio noted by Van Vianen *et al*. (2011) are 15 and 75 respectively;
  - For import iron ore terminals, the lower and upper limits of the storage factor ratio noted by Van Vianen *et al*. (2011) are 45 and 80 respectively;
  - For export coal terminals, the lower and upper limits of the storage factor ratio noted by Van Vianen *et al*. (2011) are 60 and 185 respectively;
  - For export iron ore terminals, the lower and upper limits of the storage factor ratio noted by Van Vianen *et al*. (2011) are 70 and 210 respectively.

Stockyard handling;

- Based on the user-specified stacker reclaimer configuration, the number of stacker-reclaimers are calculated based on a varied number of lanes;
- The required stockyard equipment handling capacity per handler may then be validated to be at least equal to or greater than total handling capacity at landside or seaside
- The total stockyard handling capacity may then be validated against the stockyard stacking/reclaiming capacity factors (defined as the ratio of the installed handling capacity to the minimum required capacity) outlined by Vianen *et al*. (2011) which include:
  - For import terminals, the lower and upper limits of the stockyard stacking factor noted by Van Vianen *et al*. (2011) are 5.5 and 9 respectively;
  - For import terminals, the lower and upper limits of the stockyard reclaiming factor noted by Van Vianen *et al*. (2011) are 4 and 8 respectively;
  - For export terminals, the lower and upper limits of the stockyard stacking factor noted by Van Vianen *et al*. (2011) are 3 and 4.5 respectively;
  - For export terminals, the lower and upper limits of the stockyard reclaiming factor noted by Van Vianen *et al*. (2011) are 2 and 3 respectively;
- It is noted that for the purposes of the new conceptual design too, only stacker-reclaimers were considered, and hence in the instance of an export terminal, the lower and upper limits of the stockyard factor were taken to be 2 and 4.5 respectively and for instance of an import terminal, the lower and upper limits of the stockyard factor were taken to be 4 and 9 respectively.

3.2.4.3 Module 3 – primary outputs

Following the aforementioned processes, the primary outputs of module 3 of the new conceptual design tool are

- A number of Concept Options that present possibilities in which the stockyard may be configured and sized, including the maximum width and length of each of the stockyard lanes and the width and length of the entire stockyard, including the spatial allowances for horizontal transportation systems and engineering services
- A number of Concept Options that present the stockyard handling capacity requirements including the number of stockyard handlers, their configuration (i.e. number of stockyard handlers per stockyard lane) and the required stockyard handling capacity.

In summary, the primary outputs of module 3 of the new conceptual design tool primarily relate to sizing of the stockyard and the associated stockyard handling requirements. From the generated Concept Options, the user is then able to confirm if the specified input parameters require adjustment to align with the user-specified limitations, or if from the various Concept Options, a particular output may be selected. Following the selection of an output from the generated Concept Options, module 3 will then provide the:

- The total storage area, including the number of lanes and lane dimensions;
- The required capacity per stockyard handler and the total installed landside stockyard handling capacity of the terminal;

3.3 New conceptual design tool functionality, advantages and summary

General

As previously stated in this Thesis, the new conceptual design tool is aimed at providing project developers with a range of feasible output parameters for each major infrastructure component of a dry bulk terminal. The new conceptual design tool has been developed in Microsoft Excel, so as to allow for a wide range of target users to utilize it. However, the new conceptual design tool requires a user to possess some required corresponding information such as the annual throughput capacity, the required storage capacity or the mix of vessels that may call at the terminal.

Functionality and advantages

As discussed in Section 2, although several guidelines such as those outlines by Ligteringen and Velsink (2012) and UNCTAD (1985) exist, no clear process has been proposed for the obtaining a wide range of outputs that may be used during the conceptual design process of a dry bulk terminal, without the incorporation of computer-simulation. The new conceptual design tool, developed for this Thesis incorporates the guidelines proposed by Ligteringen and Velsink (2012) and UNCTAD (1985), and incorporates the findings of Van Vianen *et al*. (2011), Van Vianen (2015) and builds upon the work undertaken by Kleinheerenbrink (2012). The new conceptual design tool allows for users and project developers to, without expending much resources and time, establish several major parameters that are key to the development of any dry bulk terminal. The new conceptual design tool also allows for a number of key inputs (which may not typically be fully determined at the conceptual design stage of any project, such as the annual throughput capacity or the handling capacity of the seaside or landside equipment) to be varied by users to understand the range of spatial and technical impacts on these major parameters. The new conceptual design tool further incorporates a number of validation checks in each module, to ensure that users are altered when inputs may be unsuitable or when Concept Options are unable to be generated.

Concept Options output summary

The new conceptual design tool generates 1,969 unique 'Concept Options' as summarized in Table 3-4. However, as each of the Concept Options is displayed on a graph, a very large number of additional Concept Options (only limited by the restrictions imposed by the user) may further be assessed through a review of the generated graphs and graph lines.

Table 3-4: New conceptual design tool Concept Option summary

Module number	Module 2 output	Variable 1	Variable 2	Fixed Variable	Concept Options generated
Module 1	Berth utilization	Number of berths	Capacity of vessel handlers	Number of handlers per	280

Module number	Module 2 output	Variable 1	Variable 2	Fixed Variable	Concept Options generated
				berth (i.e. berth configuration)	
	Berth utilization	Number of handlers per berth (i.e. berth configuration)	Capacity of vessel handlers	Number of berths	175
Module 2	Handler utilization	Number of landside handlers	Capacity of landside handlers	Number of handlers per landside transport unit (i.e. landside handler configuration)	350
Module 3	Length of stockyard lane	Number of stockyard lanes	Width of stockyard lanes	Lane height	198
	Length to width ratio of the stockyard	Number of stockyard lanes	Width of stockyard lanes	Lane height	279
	Length of stockyard lane	Number of stockyard lanes	Width of stockyard lanes	Lane height	198
	Stockyard area	Number of stockyard lanes	Width of stockyard lanes	Lane height	279
	Stockyard area	Number of stockyard lanes	Storage capacity as a percentage of annual throughput	Stockyard lane width	162
	Stockyard capacity factor (i.e. the ratio of the installed handling capacity to the minimum required capacity)	Number of stockyard handlers	N/A	Minimum required capacity	48

4 New conceptual design tool testing and analysis

This section details the outputs of the new conceptual design tool in relation to the conceptual design findings of a proposed iron ore export project in Western Australia that is also in the concept/feasibility stage. This section defines the rationale behind the selection of the project in sections 4.1 and 4.2 and presents the project background and characteristics in section 4.3. Finally, this section presents the various Concept Options from the new conceptual design tool based on the project's proposed parameters in section 4.4.

4.1 General

In order to test the functionality of the new conceptual design tool and assess its outputs it was necessary to compare the outputs from the new conceptual design tool to a factual project. The project that was chosen for this detailed comparison is the BHP Billiton Outer Harbour Development Project (BHP OHDP). The rationale for selecting this project is based on the following:

- The BHP OHDP project is a greenfield project at feasibility stage, where the terminal parameters stated are based on a conceptual design process. These terminal parameters would typically be in the same order of magnitude as the outputs of the new conceptual design tool, hence, allowing a fair comparison to be made; and
- The BHP OHDP project is a single product dry bulk terminal, which is aligned to the limitations of the new conceptual design tool;

4.2 Project background and key characteristics

BHP Billiton Iron Ore is a member of the BHP Billiton Group (BHP) which is the world's largest diversified resources company. BHP Billiton Iron Ore is one of the world's premier suppliers of iron ore and BHP's current operations in the Pilbara region in Western Australia involve a complex integrated system of seven mines, more than 1,000 km of rail and eight operating berths at the Port of Port Hedland.

In 2012, BHP proposed an ambitious plan to expand their rail network, develop a new stockyard and construct a new jetty, as part of the BHP Outer Harbour Development Project (BHP OHDP). As described in BHP's Development Justification report (BHP Billiton, 2012), the OHDP will involve construction and operation of landside and marine infrastructure for the handling and export of iron ore and includes the development of:

- rail connections and rail loops from the existing BHP Billiton Iron Ore Newman rail line to proposed stockyards at a specified location further inland (at a location named Boodarie);
- stockyards and associated infrastructure at Boodarie, including rail car dumpers, stackers, reclaimers and a screening plant;
- an infrastructure corridor (including conveyors, access roadway and utilities) from the stockyards to the proposed marine jetty (offshore from Finucane Island);
- a jetty and berths to accommodate bulk carriers offshore from Finucane Island; and
- supporting infrastructure including access roads, upgrades to existing roads and utilities, buildings, temporary construction facilities and communication systems.

The BHP OHDP project aims to function in the typical manner of an iron ore export facility. Iron ore will be transported from inland Pilbara mines along the existing BHP Billiton Iron Ore Port Hedland-Newman rail line to proposed stockyard facilities at Boodarie. Iron ore will then be offloaded from the trains by railcar dumpers and, either directly transported on overland conveyers through to the ships at the wharf facility or sent to the stockyard for storage or to the screening facilities. Ore will be carried by overland conveyors from the Boodarie stockyards to a proposed transfer station on Finucane Island, whereafter the ore will then be conveyed across the marine jetty to the berths and shiploaders to be loaded onto vessels bound for the export market.

Key project information is contained in the Table 4-1 and a graphical representation of the conceptual design and layout of the BHP OHDP is illustrated in Figure 4-1, Figure 4-2 and Figure 4-3.

Table 4-1: BHP OHDP key project information

Terminal Component	Terminal Element	Description
Marine infrastructure	Export throughput capacity	• Nominal capacity of approximately 240 million tonnes per annum (MTPA).
	Number of berths and quay length	• Eight berths; • Approximately 2 kilometres (km) in length.
	Number of ship loaders and ship loading capacity	• Four ship loaders in total; • Ship loaders to each have a with a capacity of at least 12,000t/h
Landside infrastructure	Number of landside handlers and landside handling equipment	• Five tandem railcar dumpers • Railcar dumpers capacity has not been specified
Stockyard capacity, configuration and stockyard handling	Stockyard capacity	• Not specified
	Stockyard configuration	• 10 to 11 lanes
	Stockyard handling	• 15 stacker-reclaimers

(Source: BHP Billiton, 2012)

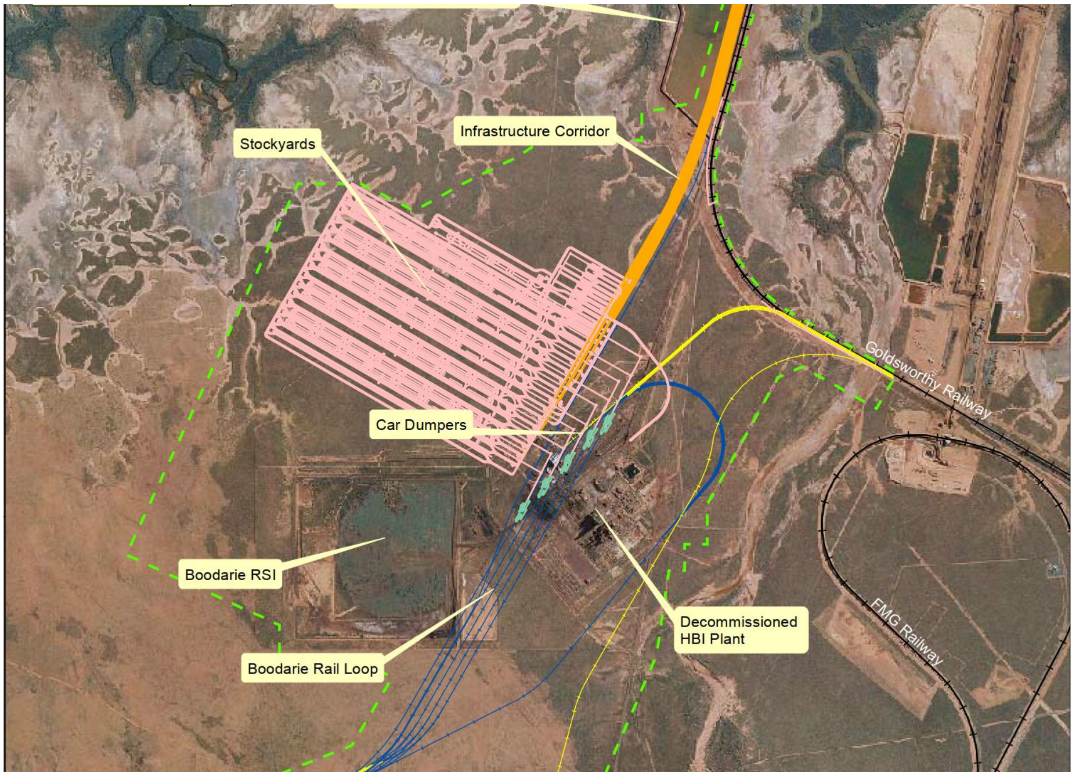

Figure 4-1: BHP OHDP stockyard conceptual layout
(Source: BHP Billiton, 2012)

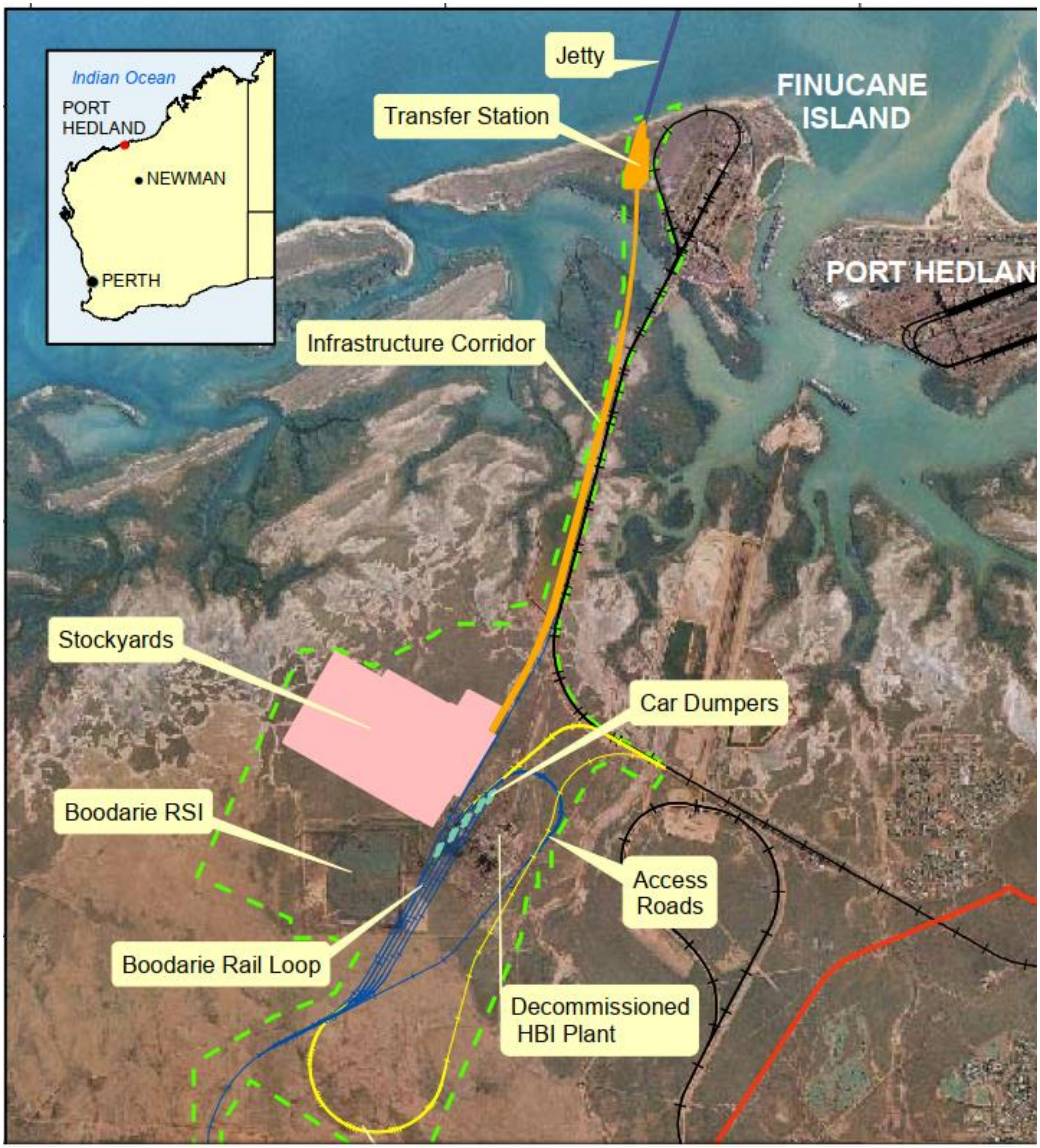

Figure 4-2: BHP OHDP project layout
(Source: BHP Billiton, 2012)

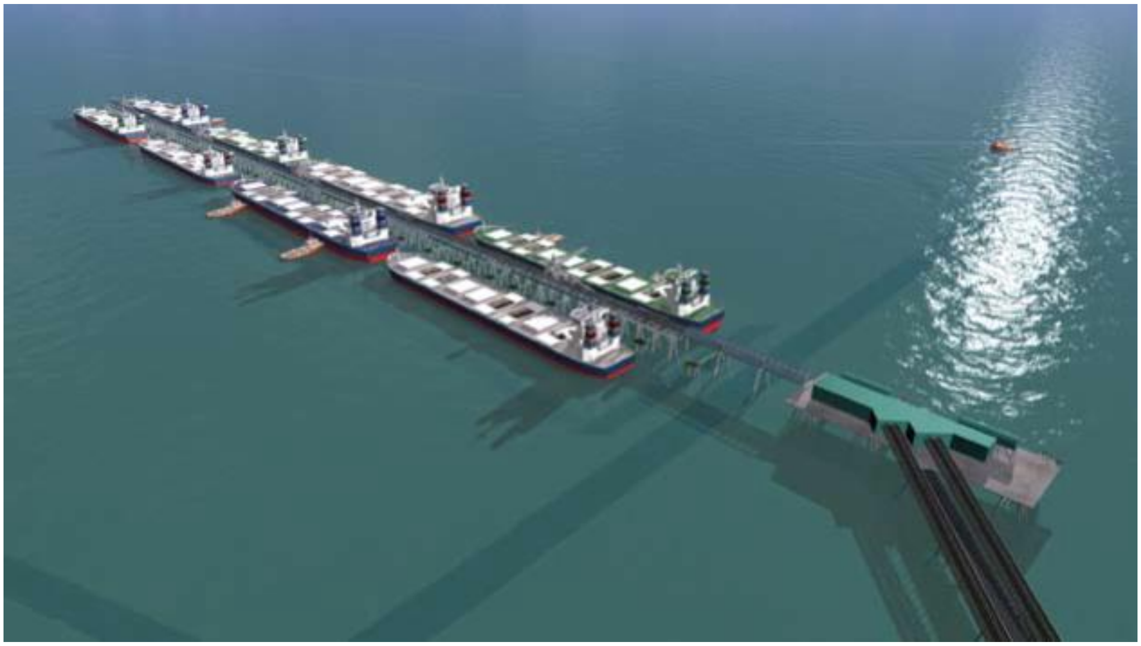

Figure 4-3: BHP OHDP jetty and berth concept

(Source: BHP Billiton, 2012)

4.3 New conceptual design tool Concept Options

The relevant key inputs and associated outputs from the new conceptual design tool and output Concept Options for two iterations of the new conceptual design tool process are described, for each of the new conceptual design tool modules, in the sections below. Initially, a summary of the key inputs and their typical ranges is described whereafter, a more detailed commentary in relation to the inputs and the generated output Concept Options is presented.

4.3.1 New conceptual design tool Concept Option input summary

Table 4-2 presents a summary of key inputs to the new conceptual design tool for the purpose of comparison with the BHP OHDP. Table 4-2 also provides typical ranges for each of the inputs and outlines the new conceptual design tool's limitations with respect to each input.

Table 4-2: New conceptual design tool inputs, input ranges and input limitations for comparison with the BHP OHDP

Module number and terminal component	Terminal element / Input	New conceptual design tool input or initial estimate	Typical input range	New conceptual design tool limitations
Module 1: Seaside handling and configuration	Type of terminal	Export	Terminals are either import, export or transhipment terminals.	The new conceptual design tool only accounts for import and export terminals.
	Commodity of terminal	Iron ore	As described in Section 1, dry bulk terminals handle major bulks and minor bulks, with export	The new conceptual design tool only allows users to select either coal

Module number and terminal component	Terminal element / Input	New conceptual design tool input or initial estimate	Typical input range	New conceptual design tool limitations
			terminals typically handling a single product only.	or iron ore as the single commodity to be handled.
	Export throughput capacity	240 million tonnes per annum	N/A, the input range of the throughput capacity is determined by the user.	The new conceptual design tool has no maximum or minimum limit on of the throughput capacity.
	Number of berths;	Eight berths.	Typically, dedicated export and import terminals around the world have a minimum of one berth, and do not exceed 8 berths, except in rare instances, such as the Qinhuangdao port in China.	The new conceptual design tool presents outputs for a minimum of one berth and a maximum of eight berths.
	Quay length	• The quay length is calculated quay length based on the average vessel length, and a factor of 1.1 as outlined by Ligteringen (1999). • The new conceptual design tool presents a Quay Length Factor "check", based on the findings of Van Vianen *et al*. (2011).		
	Shiploader configuration	0.5 shiploaders per berth (i.e. 2 berths per shiploader).	Typical input ranges for shiploader configurations span from 0.5 (i.e. one shiploader for two berths) to 2.0 (i.e. 2 shiploaders for one berth).	The new conceptual design tool limits the shiploader configuration from a minimum of 0.5 shiploaders per berth to a maximum 3 shiploaders per berth.
	Number of ship loaders	Four ship loaders in total	The number of shiploaders depends on the number of berths and the shiploader configuration. It is unlikely that the number of shiploaders will exceed the number of berths by more than a factor of 2.	The new conceptual design tool presents outputs in terms of the shiploader configuration and as such, there are no specific limits on the number of shiploaders, aside from the limits imposed by the shiploader configuration and the number of berths. Given that the new conceptual design tool is limited to a maximum of eight berths with a maximum shiploader configuration of 3 shiploaders per berth, the theoretical maximum number of shiploaders is 24.
	Ship loading capacity per shiploader	Initial estimate of 12,00t/h per shiploader	The ship loading capacity per shiploader ranges from a minimum capacity of between 400-500t/h up to a maximum capacity up to 20,000t/h (Kleinheerenbrink, 2012).	The new conceptual design tool limitations in respect of the ship loading capacity per shiploader are set at a minimum of 1,000t/h and a maximum of 20,000t/h.

Module number and terminal component	Terminal element / Input	New conceptual design tool input or initial estimate	Typical input range	New conceptual design tool limitations
	Maximum berth utilization	65% initial estimate	As detailed above in Section 3.2.2, berth occupancies should typically be below 65% for a terminal with five or less berths and an average level of control and may in some instances reach up to 70% in the case of a terminal with 6 or more berths and a higher level of arrival control by the port's administration Thoresen (2003).	The conceptual design does not limit the berth utilization but provides a "CHECK" message in instances where the input maximum berth utilization exceeds 65%.
	Maximum waiting time to service time ratio	30%	As detailed above in Section 3.2.2, waiting time should not be more than 50% of service time (Kleinheerenbrink, 2012) and is generally between 30% and 40% (UNCTAD, 1985).	The new conceptual design tool does not limit the berth utilization but provides a "CHECK" message in instances where the input maximum waiting time to service time ratio exceeds 50%.
	Effective operational days per year and working hours per day	365 days per year, 24 hours per day	• Large dry bulk terminals usually operate in excess of 360 days per year, and also continue operations 24 hours a day. • Terminals such as Richards Bay Coal Terminal and EMO Terminal operate for 365 days per year.	The new conceptual design tool limits the maximum number of operational days per year to 365, and the maximum number of operational hours per day to 24
	Vessel mix	• Handysize: 0% • Handymax: 0% • Panamax: 0% • PostPanamax: 0% • Capesize:100%	• The mix of vessels calling to the port is linked to the annual throughput of the port, the location of the port and the port ownership model. • Typically, for larger ports, Post-Panamax and larger vessels are the predominant.	The new conceptual design tool does not prescribe the vessel mix but provides a "CHECK" message in instances where the sum of the percentages for each vessel size do not equal to 100%
Module 2: Landside handling and configuration	Average capacity per landside transport unit	84 tonnes	• Rail wagons are typically 100 tonnes gross weight, with an 84 tonne carrying capacity (or payload). • Payloads may vary between 45 tonnes to as high as 120 tonnes per wagon.	The new conceptual design tool does not limit the average capacity per landside transport unit but this value it set to a default value of 84 tonnes.

Module number and terminal component	Terminal element / Input	New conceptual design tool input or initial estimate	Typical input range	New conceptual design tool limitations
	Landside handler configuration	1 handler per transport unit	• It is unlikely that there may be more than one handler per wagon. • The landside handler configuration is in place to cater for import terminals for instances with more than one discharge point (handler) into the hinterland-bound transport mode.	The new conceptual design tool does not limit the landside handler configuration but this value it set to a default value of 1 handler per transport unit.
	Maximum occupancy of handlers	85%	Typical input ranges for occupancy of landside handlers range from between 55% to a high of 90%.	The new conceptual design tool limits the maximum occupancy to 90%.
	Efficiency of the landside loader/unloader	75%	Typical input ranges for the efficiency of landside handlers range from between a low of 60% to a high of 85%.	The new conceptual design tool limits the maximum efficiency to 85%.
Module 3: Stockyard configuration and handling	Stockyard capacity in terms of the annual throughput	8% of the total annual throughput capacity	Storage capacity varies between 3% and 10% of annual throughput for export terminals and between 5% and 22% for import terminals (Van Vianen *et al*., 2011)	The new conceptual design tool limits the storage capacity to the limits prescribed by Van Vianen *et al*. (2011) and presents a "CHECK" message if the user inputs a value that falls outside of these limits.
	Maximum height of stockpile	19 metres	Kleinheerenbrink (2012), states that 90% of the stockyard machinery have a stockpile height limit of between 10m and 22.3m, with an average value of 15.2m.	• The new conceptual design tool calculates the maximum height of the stockpile based on the specified initial width and the angle of repose, and in instances where the calculated height exceeds the specified input maximum height, the specified input maximum height is used. • The new conceptual design tool presents a "CHECK" message if the specified input maximum height exceeds 23m.
	Width of a stockpile lane:	100m	The average width of stockpile lanes varies between 40m and 140m.	
	Distance between piles in the same	• 5 metres between piles in the same lane; and	• The average distance between piles varies from a minimum of 2	• Distance between piles is not limited by the new conceptual design tool,

Module number and terminal component	Terminal element / Input	New conceptual design tool input or initial estimate	Typical input range	New conceptual design tool limitations
	stockpile lane and width between adjacent stockpile lanes	• 18 metres between adjacent lanes	metres to 10 metres based on the volume of material stored at a given time. • Width between adjacent lanes is based on the rail gauge which varies between 6 and 20 meters (Schoonees *et al.,* 2020) and a spatial allowance for engineering services of between 2 and 5 metres.	but the new conceptual design tool presents a "CHECK" message if the length of the lane relative to the width of the stockyard exceeds a calculated length to width ratio. • The width between adjacent lanes is limited to a minimum of 8 metres.
	Stockyard handling configuration	1 handler per stockyard lane	The stockyard handling configuration can either be one stacker reclaimer that is able to service two stockpile lanes on either side of it or, each lane is allocated 1 or more stacker-reclaimers.	The new conceptual design tool does not limit the stockyard handling configuration but this value it set to a default value of 1 handler per lane.
	Capacity of stockyard handlers	9,000t/h	Kleinheerenbrink (2012), states that the maximum stacking and reclaiming capacities available for iron ore is 10,000 t/h and 15,000 t/h respectively, while for coal the maximum stacking and reclaiming capacities available are 10,000 t/h and 6,000 t/h respectively.	The new conceptual design tool includes a guiding note stating that the capacity of the chosen stockyard handler should not exceed 10,000t/h for coal and 15,000t/h for iron ore.

4.3.2 Module 1 – Seaside handling and configuration

4.3.2.1 Iteration 1 - Inputs

Although several inputs are required as detailed in Table 4-2, five critical inputs are required to obtain a range of Concept Options for the first module of the new conceptual design tool. These are

- **The type of terminal and terminal commodity:**
  - In the case of the BHP OHDP, this is an export terminal of a single product of iron ore;
- **The annual throughput capacity of the terminal;**
  - In the case of the BHP OHDP, this is 240MPTA;
- **The number of ship loaders/unloaders per berth:**
  - In the case of the BHP OHDP, this is 0.5, as 4 shiploaders are proposed by BHP for the 8 berths;
- **The initial estimate of the rated capacity of each of the shiploaders:**

  - In the case of the BHP OHDP, this was not disclosed as part of the prefeasibility studies, and given the magnitude of the proposed throughput, an assumption of 12,000t/h was made.

- **The maximum berth utilization of the number of berths:**
  - In the case of the BHP OHDP, this was not disclosed as part of the prefeasibility studies and was set at a default value of 60%;

4.3.2.2 Iteration 1 - Concept Option outputs

Concept Options and Sub-Concept Options

In order to develop the Concept Options for a more detailed assessment during the detailed design phases, the proposed inputs need to be tested for their practicability and achievability in an iterative manner.

For this first module, two Concept Options appear to initially exist. Firstly, the number of shiploaders per berth for the selected initial number of berths will be tested against the maximum berth utilization limits based on the initial estimated shiploading capacity. Secondly, the number of berths based on the initial shiploads per berth configuration will be assessed against the maximum berth utilization limits.

Based on the aforementioned two steps and the maximum berth utilization limit, the new conceptual design tool provides several Concept Options for the configuration of the berths for the BHP OHDP. For the sake of simplicity, the Concept Options are categorized alphanumerically in the following manner:

- Initial Concept Options are categorized by alphabet letters only.
- Sub-Concept Options are categorized by alphabet letters and numbers, where sub-options are various configurations that arise when a particular parameter is fixed.

For example, in the case of the BHP OHDP, the number of shiploaders per berth can be set at 0.5 shiploaders per berth (Concept Option 1A), and the model will then provide several berth configurations (Sub-Concept Options A1, A2, A3, A4 etc). Similarly, the number of berths can be set at 8 berths (Concept Option 1B), and the model will then provide several configurations for the number of shiploaders per berth (Sub-Concept Options B1, B2, B3, B4 etc.)

Two Concept Options may be assessed based on the initial inputs into the model. These are:

- Concept Option 1A is based on 8 berths and assesses the various numbers/configurations of shiploaders per berth as Sub-Concept Options:
- Concept Option 1B is based on a shiploader-configuration of 0.5 shiploaders per berth, and then assesses the various feasible number of berths as Sub-Concept Options.

Iteration 1 - Concept Option 1A

Concept Option 1A sets the initial estimate of the number of berths to 8, and then generates various Sub-Concept Options for varying numbers of shiploaders per berth. Each of the data points, as illustrated in Figure 4-4, is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options the following was observed:

- For 8 berths and a maximum berth utilization percentage of 60%, the feasible Sub-Concept Options are:
  - 0.5 shiploaders per berth (i.e. 4 shiploaders in total), based on a rated capacity per shiploader that exceeds 17,000 tonnes per hour; or
  - 0.75 shiploaders per berth (i.e. 6 shiploaders in total), based on a rated capacity shiploader that exceeds 11,000 tonnes per hour; or

- 1 shiploader per berth (i.e. 8 shiploaders in total), based on a rated capacity per shiploader that exceeds 8,200 tonnes per hour;
- Sub-Concept Options for two shiploaders per berth and three shiploaders per berth are also illustrated graphically but given the specific jetty layout of the BHP OHDP Project, and the proportional increase in capital expenditure of 16 or 24 shiploaders, these are not considered as feasible Sub-Concept Options.

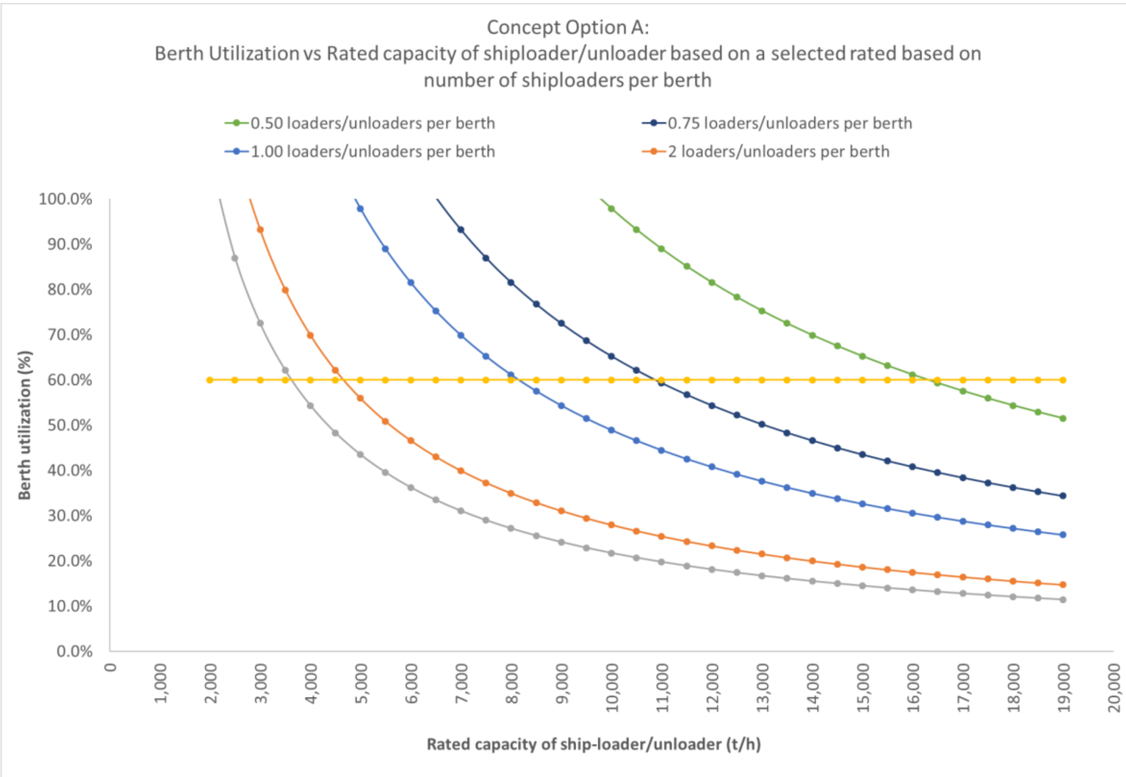

Figure 4-4: BHP OHDP Module 1 – Iteration 1 Concept Option 1A

Iteration 1 - Concept Option 1B

Concept Option 1B sets the initial estimate of the number of shiploaders per berth to 0.5 shiploaders per berth and then generates various Sub-Concept Options for varying numbers of berths. Each of the data points, as illustrated in Figure 4-5, is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options the following was observed:

- For 0.5 shiploaders per berth (or more simply, one shiploader for every two berths) and a maximum berth utilization percentage of 60%, the feasible Sub-Concept Options are:
  - 8 berths with 4 shiploaders, each at a rated capacity of 16,500t/h.
  - 7 berths, with 4 shiploaders, each with a rated capacity of 19,000t/h.
- All other Sub-Concept options with less than 7 berths require the rated capacity of shiploaders to exceed 20,000 t/h.

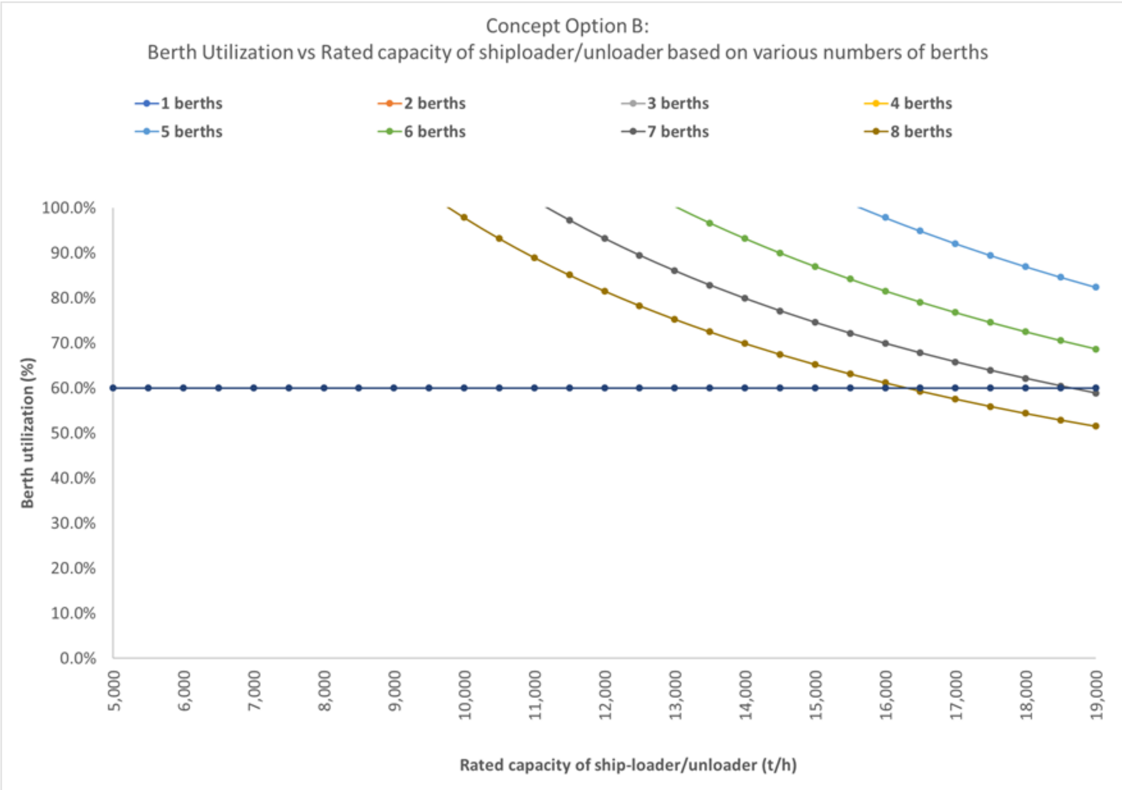

Figure 4-5: BHP OHDP Module 1 – Iteration 1 Concept Option 1B

4.3.2.3 Iteration 2 – Inputs

Based on the Concept and Sub-Concept Options generated by the first iteration, the inputs for the second iteration were varied to obtain two or three selected combinations of outputs that may then be assessed by project developers during the detailed design phases.

Only one of the inputs was changed in the second iteration, namely the maximum berth utilization limits. This was changed to a higher maximum berth utilization level of 75%. (from 60% in iteration 1)

4.3.2.4 Iteration 2 - Concept Option outputs

Iteration 2 - Concept Option 1A

As mentioned above, Concept Option 1A sets the initial estimate of the number of berths to 8, and then generates various Sub-Concept Options for varying numbers of shiploaders per berth. For this second option, based on a higher maximum berth utilization, each of the data points as illustrated in Figure 4-6 is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options, the following was observed:

- For 8 berths and a maximum berth utilization percentage of 75%, the Sub-Concept Options are:
  - 0.5 shiploaders per berth (i.e. 4 shiploaders in total), based on a rated capacity per shiploader that exceeds 13,000 tonnes per hour; or

- 0.75 shiploaders per berth (i.e. 6 shiploaders in total), based on a rated capacity shiploader that exceeds 9,000 tonnes per hour; or
- 1 shiploader per berth (i.e. 8 shiploaders in total), based on a rated capacity per shiploader that exceeds 6,500 tonnes per hour;

In reality, a berth utilization of over 60% would generally result in lengthier waiting times for vessels or increased demurrage costs, and as such the selected berth utilization of 75% may be unrealistic. However, for the purposes of this comparison, this maximum berth utilization was used. Given that the proposed feasibility study for the BHP OHDP has stated that 4 shiploaders will be employed, this option is selected, and it is proven to be feasible by the new conceptual design tool, should the rated capacity of shiploaders exceed 13,000 tonnes per hour and the berth utilization not exceed 75%.

The selected combination of 4 shiploaders is also indicated in Figure 4-6.

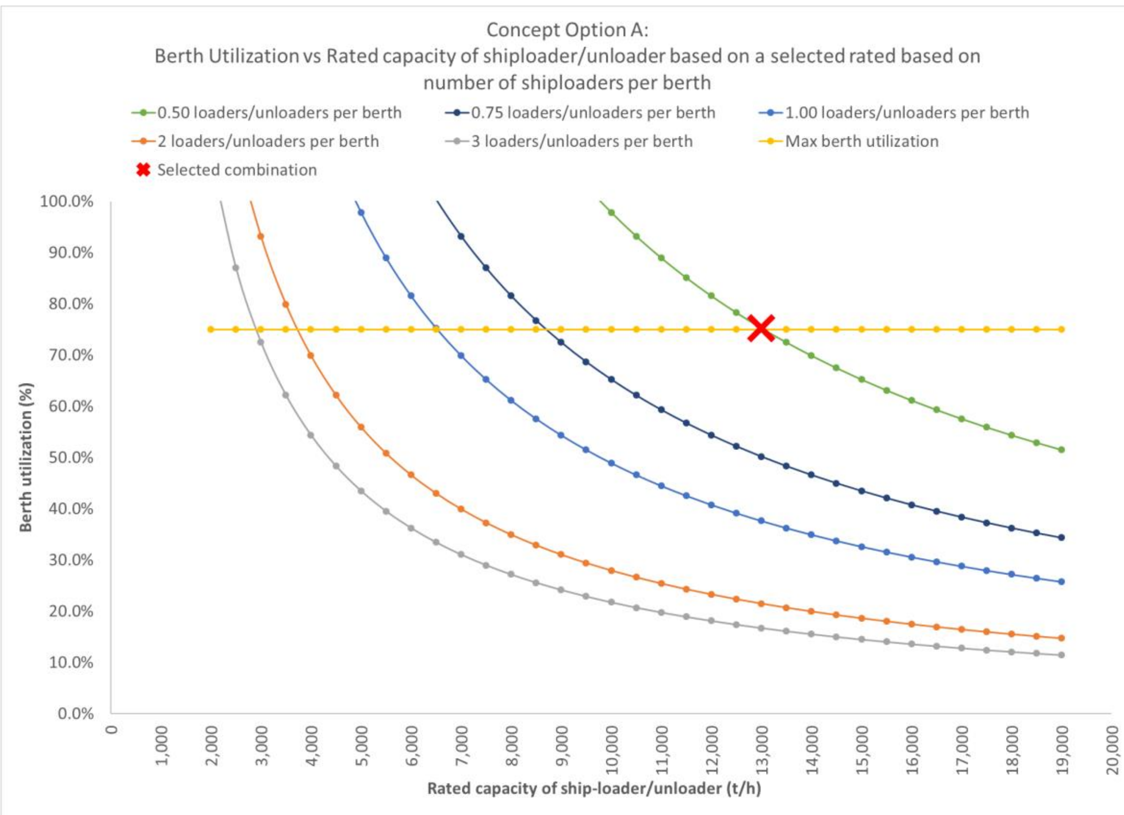

Figure 4-6: BHP OHDP Module 1 – Iteration 2 Concept Option 1A

Iteration 1 - Concept Option 1B

As mentioned above, the option of 0.5 shiploaders per berth has been selected. Based on this selection, Concept Option 1B generates various Sub-Concept Options for varying numbers of berths. Each of the data points as illustrated in Figure 4-7 is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options, the following was observed:

- For the selected option of 0.5 shiploaders per berth (or more simply, one shiploader for every two berths) and a maximum berth utilization percentage of 75%, the Sub-Concept Options are:
  - 8 berths with 4 shiploaders, each at a rated capacity of 13,000t/h
  - 7 berths, with 4 shiploaders, each with a rated capacity of 15,000t/h.

Given that the proposed feasibility study for the BHP OHDP has stated that 8 berths will be employed, this option is selected, and it is proven to be feasible by the new conceptual design tool, should the rated capacity of shiploaders exceed 13,000 tonnes per hour. Although some shiploader manufacturers have stated that there are shiploaders capable of exceeding 16,000t/h, they are increasingly rare for iron ore loading terminals, and hence the option of shiploaders with capacities of 13,000t/h appears more suited to the loading iron ore for the BHP OHDP. The selected combination of the 4 shiploaders is also indicated in **Figure 4-7**.

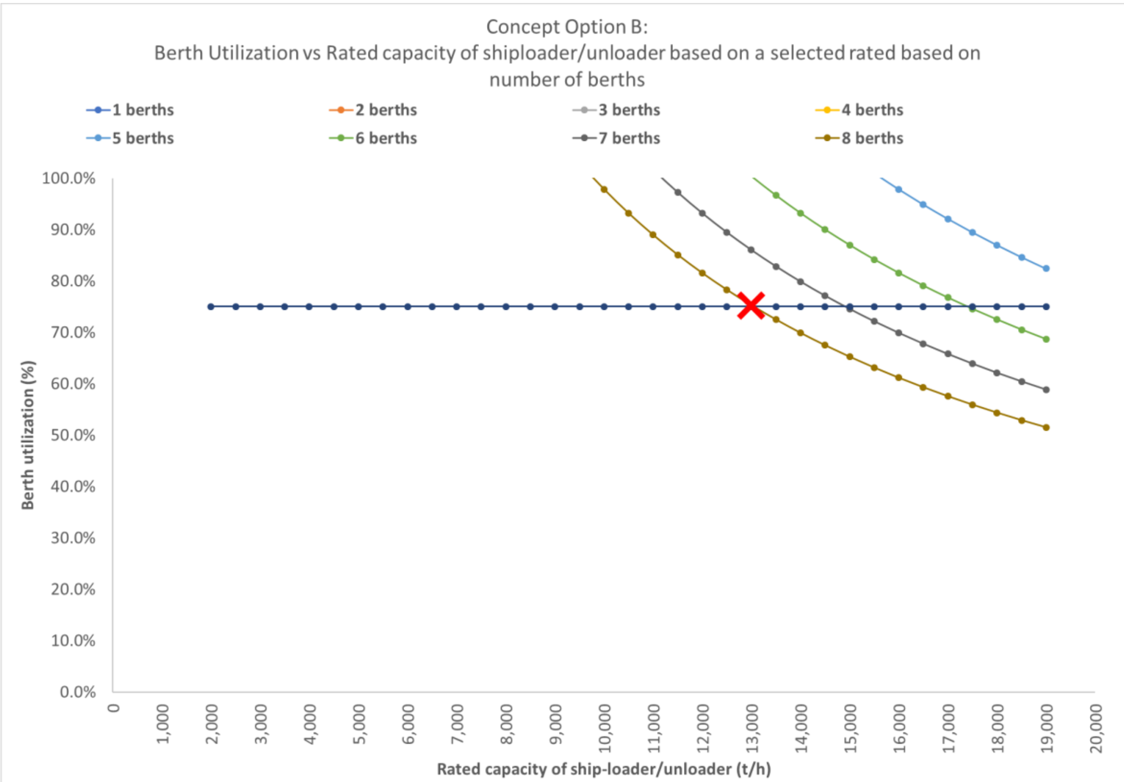

Figure 4-7: BHP OHDP Module 1 – Iteration 2 Concept Option 1B

4.3.2.5 New conceptual design tool Module 1 outputs

Table 4-3 provides the outputs of Module 1 of the new conceptual design tool, based on the two iterations as explained above.

Table 4-3: BHP OHDP Module 1 outputs

Output Element	Unit	Value
Terminal Information		
Annual terminal throughput capacity	*MTPA*	240
Average vessel size	*Deadweight tonnes*	220,000[1]
Average vessel length	*metres*	266
Average vessel beam	*metres*	41

[1] BHP have indicated that it expects primarily Capesize vessels to dock (BHP Outer Harbour Development Project, 2012)

Output Element	Unit	Value
Average vessel draught	*metres*	16
Berth and quay length outputs		
Number of Berths	*number*	8
Quay length	*metres*	2,490
Quay length factor	*ratio*	96.38
Quay length factor check	*validation*	OK
Shiploading outputs		
Number of loaders/unloaders per berth	*number*	0.50
Total number of loaders/unloaders	*number*	4
Total installed handling capacity of terminal	*tonnes/hour*	52,000
Rated capacity per loader/unloader	*tonnes/hour per (un)loader*	13,000
Effective handling rate per berth (based on through ship efficiency factor)	*tonnes/hour per (un)loader*	4,550
Effective handling capacity of terminal	*tonnes/hour*	36,400
Minimum required loading / unloading capacity	*tonnes/hour*	27,397
Loading / unloading factor (ratio of installed to minimum)	*ratio*	1.90
Loading / unloading factor check	*validation*	OK
Berth utilization outputs		
Berth occupancy / utilization desired max	*%*	75.%
Berth occupancy / utilization	*%*	75.3%
Berth occupancy / utilization check	*validation*	OK

4.3.3 Module 2 – Landside handling and configuration

4.3.3.1 Inputs

Although several inputs are required as detailed in Table 4-2, four critical inputs are required to obtain a range of Concept Options for the second module of the new conceptual design tool. These are:

- **The average tonnage of a single unit of landside transport:**
  - In the case of the BHP OHDP, landside transport is via railcars, and an average net wagon tonnage of 84 tonnes (i.e. 84 tonnes of iron ore can fit into one wagon) was selected.

- **The number of railcar wagons per railcar dumper / rotary tippler:**
  - Typically, railcar dumpers or rotary tipplers are tandem tipplers (as outlined in Section 3.2.3). However, in the case of the new conceptual design tool, the number wagons per railcar dumper has been limited to one so as to ascertain the required landside handling capacity more easily.

- **The maximum occupancy of landside unloaders:**
  - In the case of the BHP OHDP, a value for the maximum occupancy has not been provided. It is assumed that this is in the region of 80% - 90%, given that railcar dumpers / landside handlers typically work continuously in iron ore export terminals.

- **The efficiency of the landside loader/unloader:**
  - Given that the railcar wagons are required to be positioned prior to being emptied, the rated capacity of the landside unloader per hour can never be the same as the actual capacity of the landside unloader per hour. Thus, an efficiency factor has been introduced and it was assumed that this is in the region of 70-80%.

4.3.3.2 Concept Option outputs

Concept Options and Sub-Concept Options

For this second module, only one Concept Option is possible (with various Sub-Concept Options). This is the variation of the number of landside unloaders and their respective capacities in the context of:

- the limitation of one landside unloader per wagon;
- the required throughput tonnage that is to be achieved; and
- the maximum limits of the utilization of the landside unloaders.

As mentioned above, Concept Option 2A for module 2 generates various Sub-Concept Options for varying numbers of landside handlers based on varying rated unloading capacities. Each of the data points as illustrated in Figure 4-8 is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options, the following was observed:

- For one landside handler per wagon and a maximum landside handler utilization percentage of 75%, the feasible Sub-Concept Options range from 10 landside handlers, each at a capacity of 5,000t/h to 6 landside handlers, each at a capacity of close to 9,000t/h.
- Sub-Concept Options for 5 landside handlers and 4 landside handlers are also illustrated graphically, but these options are not considered as they require landside handling capacities per wagon that are generally in excess of the capacities of landside unloaders for export terminals.

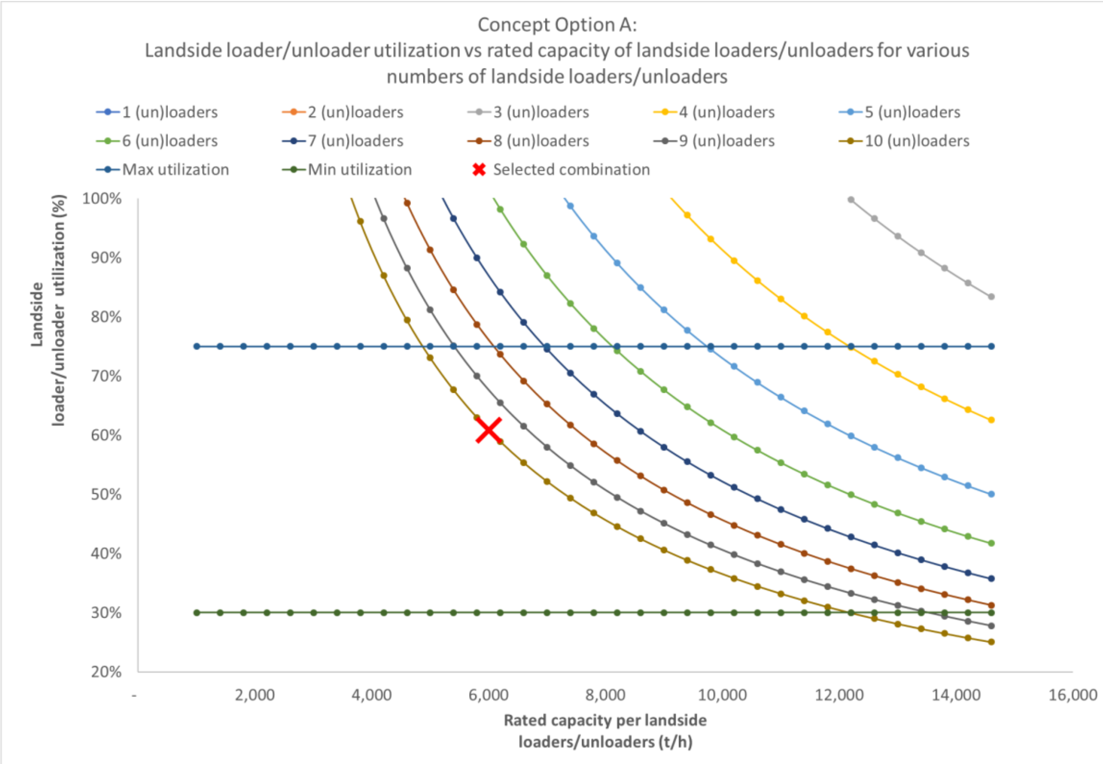

Figure 4-8: BHP OHDP Module 2 – Concept Option 2A

Given that only one iteration is required for this module, a selected option of 10 landside unloaders at a capacity of 6000t/h is chosen, and this is also represented in Figure 4-8. This chosen option may translate to five tandem tipplers at a capacity of 6000t/h, or three tridem tipplers (tipplers that tip three wagons at a time) at a capacity of 6,600t/h. Further, it was noted that the BHP OHDP project proposed that five tandem tipplers be used, which is confirmed to be viable by the outputs of the new conceptual design tool.

4.3.3.3 New conceptual design tool Module 2 outputs

Table 4-4 provides the outputs of Module 2 of the new conceptual design tool as explained above.

Table 4-4: BHP OHDP Module 2 outputs

Output Element	Unit	Value
Landside transport outputs		
Wagon tonnage	*tonnes*	84
Required landside handling capacity per hour (based on throughput capacity)	*tonnes/hour*	27,397
Required number of wagons to be loaded/unloaded per hour	*number*	326.2
Landside loading/unloading outputs		
Number of wagons loaded/unloaded per hour	*number*	536
Number of landside loaders/unloaders per wagon	*number*	1
Total number of landside loaders/unloaders (tandem tipplers count as two loaders/unloaders)	*number*	10
Rated capacity per landside loader/unloader	*tonnes/hour*	6,000

Output Element	Unit	Value
Total rated capacity of landside loaders/unloaders	*tonnes/hour*	60,000
Efficiency of landside loaders/unloaders	*percentage*	75%
Total actual capacity per landside loaders/unloaders	*tonnes/hour*	4,500
Total actual capacity of landside loaders/unloaders	*tonnes/hour*	45,000
Time taken to load/unload one wagon of given capacity	*seconds*	67
Landside handler utilization		
Maximum landside loader/unloader utilization	*percentage*	75%
Landside handler occupancy rate	*percentage*	61%
Loader/unloader utilization rate check	*validation*	OK
Loading/unloading factor validation		
Loading/unloading factor	*ratio*	1.643
Loading/unloading factor check	*validation*	OK

4.3.4 Module 3 – Stockyard configuration and handling

4.3.4.1 Inputs

Although several inputs are required as detailed in Table 4-2, six critical inputs are required to obtain a range of Concept Options for the third module of the new conceptual design tool. These are

- **The maximum percentage of the annual throughput that may be required to be stored at the terminal:**
  - According to Van Vianen *et al*. (2011), typically for export terminals, the storage capacity varies between 3% and 10%.
  - In the case of the BHP OHDP, this was not specified, but based on Van Vianen *et al*. (2011), the typical storage factors (i.e. the ratio of tonnes of commodity to the areas of the stockyard) for iron ore export terminals, an assumption of 8% of the annual throughput was made.

- **The maximum height of the stockpile:**
  - In the case of the BHP OHDP, as specific stacker-reclaimer units were not specified, it is assumed that, given the relatively large annual throughput, the initial stacker-reclaimer stockpile limit may be set at 19m.

- **The average width of a stockpile lane:**
  - Given that the throughput for the BHP OHDP is relatively high in comparison to other iron ore terminals (almost 4 times the throughput of Saldanha), lane widths is assumed to be 100m.

- **The average distance between piles in the same stockpile lane:**
  - The number of piles per lane is thus calculated by dividing the total number of piles by the number of lanes, and from findings of the terminals examined (as outlined in Section 2.9) an average distance of 5m between adjacent piles has been inserted as an input for this module 3.

  - From the selected terminals assessed (as outlined in Section 2.9) an average distance of 5m between adjacent piles has been observed and this may be inserted in relation to this input for this module 3.

- **The average width between adjacent stockpile lanes**
  - In the case of the BHP OHDP, the average width between adjacent stockpile lanes including the width allocation for the stacker-reclaimer rail track and for utilities and services has been inserted as 18 metres. This is based on a rail track width of 15m which is within the rail gauge width range of between 6m and 20m outlined by Schoonees *et al*. (2020) and a 3m allowance for utilities and engineering services, based on an estimate of 1m width allowance each of water, power and stormwater conduits (Aldous, 2020).

- **The stacker-reclaimer configuration and rated capacity**
  - In the case of the BHP OHDP, although the proposed number of stacker-reclaimers exceeded the number of proposed lanes an initial configuration of 1 stacker-reclaimer per stockpile lane initially assumed. It is noted that in many locations (such as at Ponta da Madeira, Brazil or at the Port of Qinhuangdao, China there is more than one stacker-reclaimer per stockpile lane, and in some locations such as at Richards Bay Coal Terminal, there is less than one stacker-reclaimer per stockpile lane). However, an initial estimate of one stacker-reclaimer per stockpile lane was chosen as a point of departure, after which the generated Concept Options will indicate if the initial estimate is viable.
  - In the case of the BHP OHDP, the initial estimate of the stacker-reclaimer capacity is 9,000 t/h, which is within the upper limit of the range of the stacking and reclaiming capacities of 10,000 t/h and 15,000 t/h respectively (Kleinheerenbrink, 2012).

4.3.4.2 Concept Option outputs

Concept Options and Sub-Concept Options

For the third module, a number of Concept Options for the stockyard configuration may developed. Three Concept Options relate to the stockyard configuration, while a fourth option relates to the stockyard handling arrangement. The Concept Options are summarized below:

- **Concept Option 3A:**
  - Concept Option 3A is based on the fixed stockpile height and storage capacity (as a percentage of annual throughput) as set in the inputs, a range of stockpile lengths are generated for varying stockpile widths and stockpile lane numbers.

- **Concept Option 3B**
  - Concept Option 3B is based on the fixed stockpile height and storage capacity (as a percentage of annual throughput) as set in the inputs, a range of stockpile length to width ratios are generated for varying stockpile widths and stockpile lane numbers.

- **Concept Option 3C:**
  - Concept Option 3C is based on the fixed stockpile height and a set lane width (as informed by Concept Options 3A and 3), a range of the stockyard areas are generated for varying storage capacities and stockpile lane numbers.

- **Concept Option 3D**
  - Concept Option 3D is based on the fixed stockpile height, the set lane widths (as informed by Concept Options 3A and 3), a range of the stockyard handling capacity ratios are generated for varying numbers of stockyard handlers.

Concept Option 3A

Concept Option 3A sets the initial height of 19m and the storage capacity to 8% of annual throughput and then generates various Sub-Concept Options for varying lane lengths and varying numbers of stockyard lanes. Each of the data points as illustrated in Figure 4-9, is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options the following was observed:

- Stockpile widths below 80m for 15 stockpile lanes or less are not feasible given that the length of the stockpile lane, in that instance (for the proposed storage capacity of 8% of annual throughput), is in excess of 2,400m, which results in the length to width ratio being exceeded.
- Only stockyard configurations of between 8 and 15 lanes are feasible given the limits on both the length and the widths of stockpile lanes (note that in extreme scenarios, the width of stockpile lanes may only reach up to 140m).
- The initial estimated width of the stockpile lanes of 100m generates the following specific Sub-Concept Options:
  - 15 lanes, at 100m wide and 1,670m long;
  - 13 lanes, at 100m wide and 1,930 m long;
  - 11 lanes, at 100m wide and 2,280m long;
  - 9 lanes, at 100m wide and 2,790m long;

Sub-Concept Options for 9 lanes or less are also illustrated graphically but given the widths and lengths of the stockpile lanes required, these are not considered as feasible Sub-Concept Options.

The initial estimate of 100m wide lanes provides a Sub-Concept Option output of 10 lanes at lengths of circa 2,500m and this is also represented in Figure 4-9. The BHP OHDP project proposed either 10 or 11 stockpile lanes, with an estimated lane width of 120m and a resultant (measured) lane length of circa 1,900m[2]. When this proposal is applied into the new conceptual design tool, the resultant output is a lane length of 1,934m which is within 2% of the proposed lane length in the BHP OHDP feasibility document.

[2] Note that the lane length has been measured from the 'to scale' conceptual layout of the BHP OHDP, as presented by BHP in 2012.

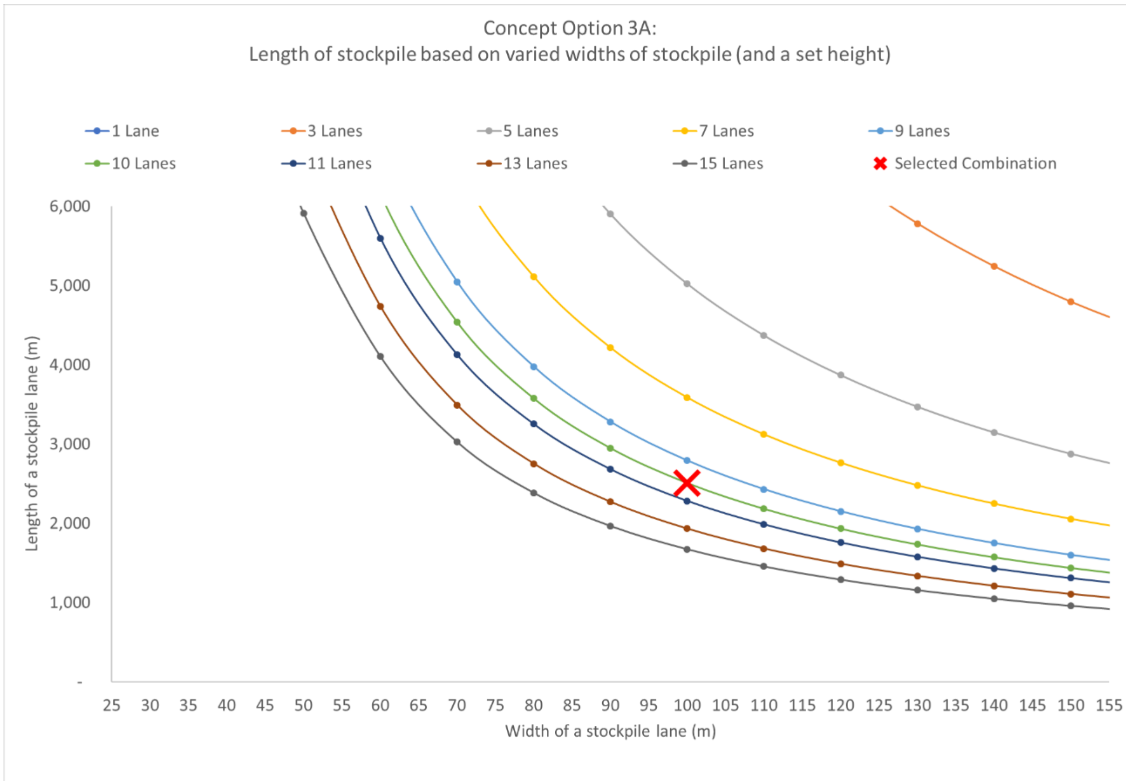

Figure 4-9: BHP OHDP Module 3 –Concept Option 3A

Concept Option 3B

Concept Option 3B sets the initial height at 19m and the storage capacity at 8% of annual throughput and generates a range of stockpile length to width ratios for varying stockpile widths and stockpile lane numbers. Each of the data points, as illustrated in Figure 4-10, is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options the following was observed:

- Although the length to width ratio limits as shown in Figure 4-10 appear to illustrate that at the extreme lane widths of 55m and 150m are within the limits, the rationale described in Concept 3A should be considered, where lane widths exceeding 140m are typically not considered.
- The average length to width ratio limit of 2.6 as shown in Figure 4-10 indicates that a stockyard configuration ranging from 15 lanes with lane widths of 70m each to 10 lanes with lane widths of about 120m are feasible.
- The minimum and maximum length to width ratios as shown in Figure 4-10 are 1.17 and 4.95 respectively;
- The initial lane width estimate of 100m generates the following Sub-Concept Options:
  - 15 lanes, at 100m width, at a length to width ratio that is less than the minimum length to width ratio;
  - 13 lanes, at 100m width that is equal to length to width ratio of 1.34;
  - 11 lanes, at 100m width that is equal to length to width ratio of 1.85
  - 9 lanes, at 100m width that is equal to length to width ratio of 2.75, which is closest to the average length to width ratio of 2.65; and
  - 7 lanes, at 100m width that is equal to length to width ratio of 4.53, just below the maximum length to width ratio.

Sub-Concept Options of less than 7 lanes generate options that fall outside the maximum length to width ratio limit, and thus may be considered to be unfeasible options.

The initial estimate of 100m lanes generates a Sub-Concept Option of 10 lanes and a length to width ratio of 2.24. This ratio is within the maximum and minimum length to width ratio limits and is relatively close to the average length to width ration of 2.65.

Given that the BHP OHDP has proposed a (measured) total stockyard width of circa 1200m[3], the resultant length to width ratio is 1.6. This is within the length to width ratio limits and can be confirmed to be a feasible Sub-Concept option by the new conceptual design tool.

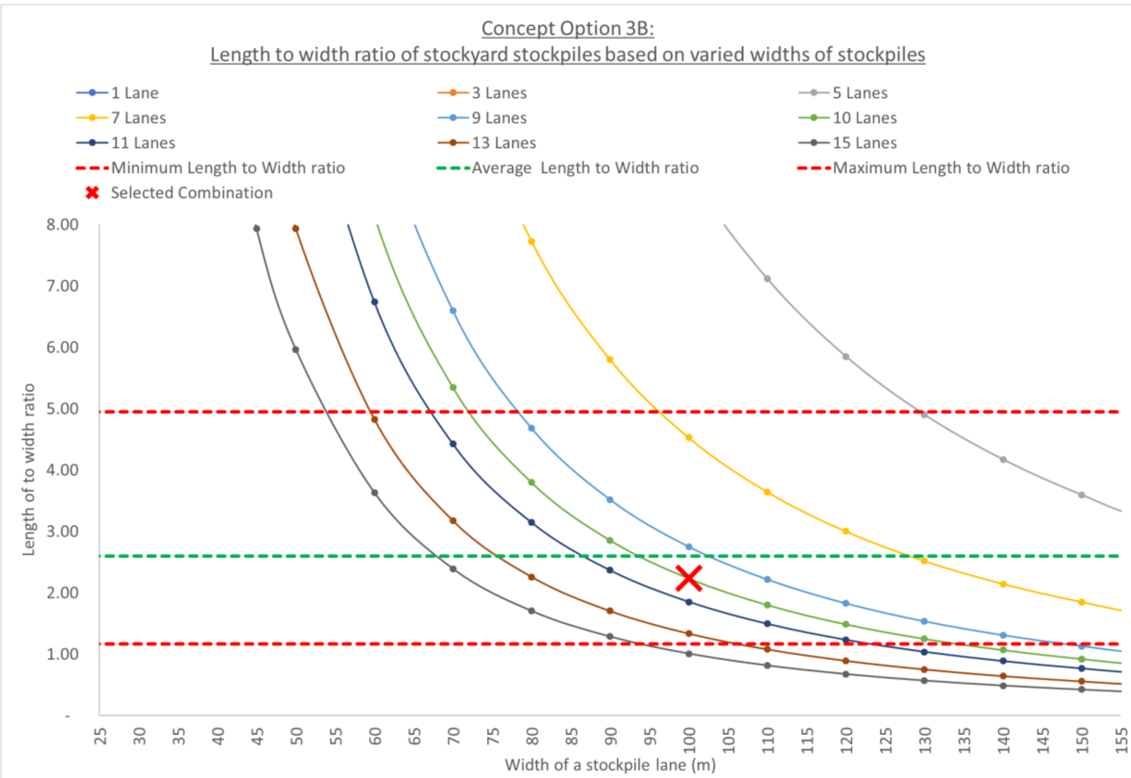

Figure 4-10: BHP OHDP Module 3 –Concept Option 3B

Concept Option 3C

Concept Option 3C sets the initial height at 19m and the lane width at the initial estimate of 100m generates a range of the stockyard areas for varying storage capacities (as a percentage of annual throughput) and stockpile lane numbers. Each of the data points, as illustrated in Figure 4-11, is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options, the following was observed:

- The minimum and maximum storage capacity limits as shown in Figure 4-11 are illustrated by the vertical lines, at 2.3% and 11% of annual throughput respectively;

[3] Note that the stockyard width has been measured from the 'to scale' conceptual layout of the BHP OHDP, as presented by BHP in 2012.

- Based on the storage factors derived by Van Vianen *et al.* (2011), the minimum and maximum storage areas as shown in Figure 4-11 are illustrated by the horizontal lines at circa 1 million m^2 (100 hectares) and 3.7 million m^2 (370 hectares) respectively.
- The aggregation of these two limits produces a 'box' of feasible Sub-Concept Options, for various stockyard configurations. This 'box' of feasible Sub-Concept Options indicates the range of stockyard capacities and associated stockyard area requirements that are feasible.

For the initial storage capacity of 8% of the annual throughput capacity, the associated stockyard area will be between 300 and 320 hectares for stockyard configurations of 7 to 15 lanes. For the BHP OHDP, the proposed stockyard area based on the previously stated (measured) length and widths equates to circa between 2.4 million m^2 (240 hectares) and 2.6 million m^2 (260 hectares). Given that the new conceptual design tool makes generous allowances for rail gauge widths, utilities and services, the variance of circa 13% between the proposed stockyard area and the stockyard area generated by the design tool can be well-understood.

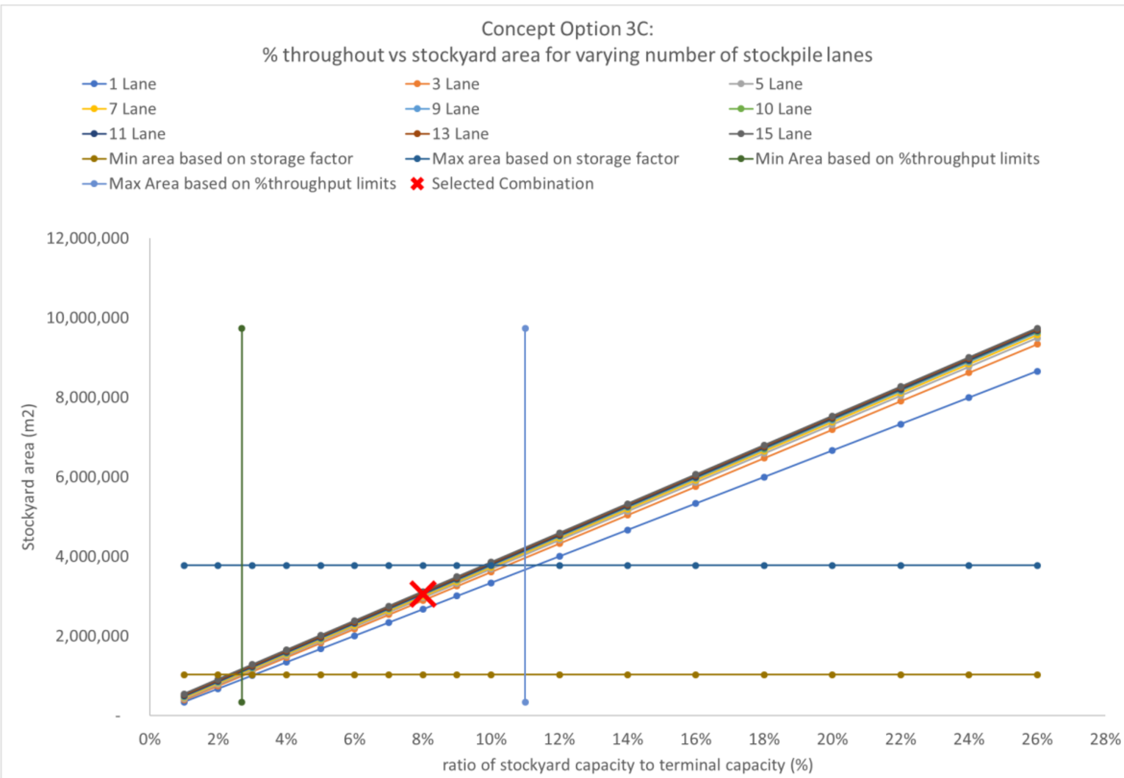

Figure 4-11: BHP OHDP Module 3 – Concept Option 3C

Concept Option 3D

Concept Option 3D sets the initial height of 19m, storage capacity to 8% of the annual throughput and the stockyard configuration obtained from the outputs of Concept Options 3A, 3B and 3C, and generates a range of stockyard capacity factors based on a varying number of stockyard handlers.

For the purposes of the new conceptual design tool, all stockyard handlers are assumed to have the dual-functionality of stacking and reclaiming and are assumed to be stacker-reclaimers. Although in practice, for an export terminal, it is likely that there may be more reclaiming machinery than stacking/stacker-reclaiming machinery, this assumption allows the project developers to understand the required stacking-reclaiming requirements, both in terms of asset numbers and required capacity (tonnage per hour). For the new conceptual design tool the configuration of stockyard handlers may be changed by the user at will, thus allowing for the project developers to explore various stockyard handling configurations and assess the impact of this on their capital investment relating to the acquisition of a certain number of stockyard handlers.

Each of the data points. as illustrated in **Figure 4-12**, is a Sub-Concept Option. To assess the feasibility of these initial Sub-Concept Options, the following was observed:

- Given the number of lanes selected as the desired Sub-Concept Option in Concept Option 3C, the minimum number of stacker-reclaimers that may be employed is five (if a configuration of 1 stacker-reclaimer for every two stockpiles is chosen).
- The minimum and maximum stockyard handling capacity factors of 1.8 and 5 respectively are also illustrated, based on the findings of Van Vianen *et al*. (2011).
- Based on the minimum and maximum stockyard handling factors, the following Sub-Concept Options are generated:
  - 8 stacker reclaimers, with a stockyard capacity factor of 1.9;
  - 10 stacker reclaimers, with a stockyard capacity factor of 2.4;
  - 12 stacker reclaimers, with a stockyard capacity factor of 2.8;
  - 14 stacker reclaimers, with a stockyard capacity factor of 3.3;
  - 16 stacker reclaimers, with a stockyard capacity factor of 3.8;

The initial estimate of 1 stacker-reclaimer per lane (i.e. 10 stacker-reclaimers) appears to be within the limits imposed by the storage capacity factors and also satisfies (and exceeds) the minimum requirement of 5 stacker-reclaimers. In addition, the 15 stacker-reclaimers as proposed by BHP for the BHP OHDP also appears to be within the limits, as shown in Figure 4-12.

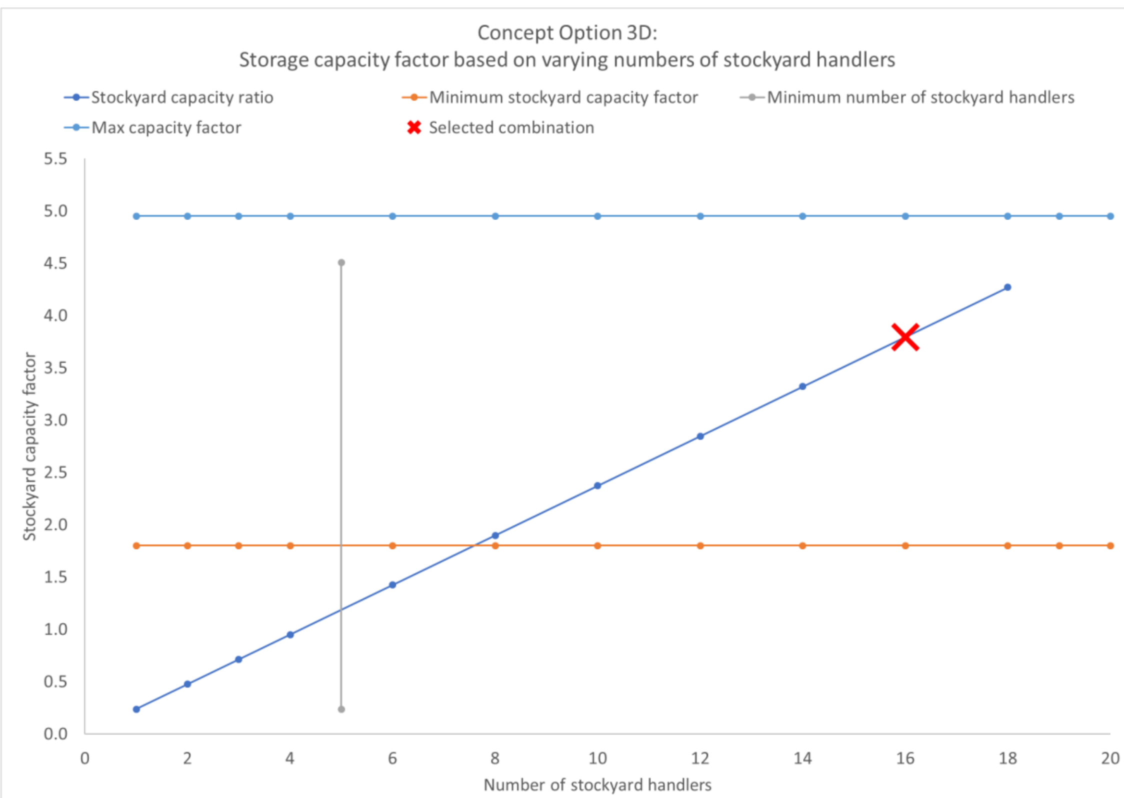

Figure 4-12: BHP OHDP Module 3 – Concept Option 3D

4.3.4.3 New conceptual design tool Module 3 outputs

Table 4-5 provides the outputs of Module 3 of the new conceptual design tool as explained above.

Table 4-5: BHP OHDP Module 3 outputs

Output Element	Unit	Value
Stockyard configuration		
storage capacity	tonnes	19,200,000
% of throughput required in storage	%	8.0%
% of throughput required in storage (min)	%	2.7%
% of throughput required in storage (max)	%	11.0%
% of throughput required in storage (check)	validation	OK
Number of stockpile lanes	number	10
Width of stockpile lanes	metres	100
Height of stockpiles	metres	19
Number of piles per stockpile lane	metres	18
Width between adjacent piles within the same stockpile lane	metres	5
Length of stockpile lanes (also length of stockyard)	metres	2,611.34
Stacker-reclaimer rail gauge width	metres	15.00
Width between adjacent stockpile lanes for services/conveyors	metres	3.00
Total width between adjacent stockpile lanes	metres	18.00
Total width of stockyard (including stockpile widths, rail gauges and services)	metres	1,168.00
Min Length to width ratio (from literature)	ratio	1.17
Max Length to width ratio (from literature)	ratio	4.95
Length to width ratio	ratio	2.24
Length to width ratio check	validation	OK
Total area of stockyard	square metres	3,050,040.68
Min area based on max storage factor	square metres	1,028,571.43
Max area based on minimum storage factor	square metres	3,771,428.57
Stockyard area check based on storage factors	validation	OK
Stockyard Handling		
Stacker Reclaimer configuration (1 per lane or 1 per two lanes)	ratio	1.00
Number of stacker reclaimers	number	10
Total rated capacity of landside handlers	tonnes/hour	60,000.00
Rated capacity per landside handlers	tonnes/hour	6,000.00

Output Element	Unit	Value
Total rated capacity of seaside handlers (all berths and all handlers)	tonnes/hour	52,000.00
Total rated capacity of seaside handlers per berth	tonnes/hour	6,500.00
Stacking/reclaiming capacity per stockyard handler	tonnes/hour	6,500.00
Total stacking/reclaiming capacity of all stockyard handlers	tonnes/hour	65,000.00
Stockyard capacity check	validation	OK
Stockyard capacity factor (combined stacking and reclaiming)	ratio	2.37
Minimum capacity factor	ratio	1.80
Maximum capacity factor	ratio	4.95
Stockyard handling capacity factor check	validation	OK

4.4 BHP OHDP characteristics compared to new conceptual design tool outputs

Based on the range of Concept and Sub-Concept Options generated by the new conceptual design tool and explained above, the present sub-section tabulates the selected combinations of each of the modules and compares that to the proposed project parameters for the BHP OHDP project. This comparison is shown in Table 4-6. It is observed that the conceptual design output compares well with the proposed project parameters as outlined in the BHP OHDP feasibility presentation (BHP, 2012). It should be noted that for a comparative assessment to be undertaken between the outputs of the conceptual design too and the proposed parameters for the BHP OHDP, a single Concept Option for each of the major terminal components was chosen from the generated range of Concept Options, with this chosen Concept Option listed in Table 4-6

Table 4-6: BHP OHDP key project information compared to the new conceptual design tool

Terminal Component	Terminal Element	Description	Conceptual design output
Marine infrastructure	Export throughput capacity	• Nominal capacity of approximately 240 MTPA.	• N/A
	Number of berths and quay length	• Eight berths; • Approximately 2,000m in length.	• Eight berths • Approximately 2,490m in length.
	Number of ship loaders and ship loading capacity	• Four ship loaders in total; • Ship loaders to each have a with a capacity of at least 12,000t/h	• Four ship loaders in total; • Ship loading capacity at 13,000t/h
Landside infrastructure	Number of landside handlers and landside handling equipment	• Five tandem railcar dumpers • Railcar dumpers capacity has not been specified	• Five tandem railcar dumpers • Railcar dumping capacity at 6,000 t/h
Stockyard capacity, configuration and stockyard handling	Stockyard capacity	• Not specified	• 8% of annual throughput (i.e. 19 million tonnes)
	Stockyard configuration	• 10 to 11 lanes	• 10 lanes
	Stockyard handling	• 15 stacker-reclaimers at unspecified stacking and reclaiming capacities	• 10 stacker-reclaimers, at an average stacking-reclaiming capacity of 9,000 t/h

Terminal Component	Terminal Element	Description	Conceptual design output
	Stockyard area	• Not specified	• 300 hectares
	Number of piles (i.e. number of grades of ore)	• Not specified	• Up to a total of 180 'identity preserved' piles.

(Source: BHP Billiton, 2012)

5 Comparison of operating terminals to the outputs of the new conceptual design tool

This section presents a comparison of the results of the new conceptual design tool to several terminal configurations globally. The comparison between the model outputs and the configurations of the seven terminals are summarized in the sections below, in descending order based on their annual throughput capacity. Section 5.1 outlines the rationale behind the selection of the terminals and section 5.2 presents the approach to undertaking the comparison. Section 5.3 and Section 5.4presents the results of the comparisons and the analysis of comparative results respectively.

5.1 General

As shown in the previous section, the new conceptual design tool provided outputs that are comparable to the output design parameters for a dry bulk terminal project that is in the feasibly / conceptual design phase. However, to illustrate the functionality of the new conceptual design tool, it is necessary to compare the tool's outputs to the characteristics of operational dry bulk terminals around the world.

To illustrate the generic and flexible nature of the new conceptual design tool, terminals with a range of annual throughput capacities from 18MTPA to 120MPTA were selected. Import and export iron ore and coal terminals were selected to illustrate the ability of the new conceptual design tool in respect of accounting for at least two different commodities (i.e. iron ore and coal) and two terminal types (i.e. import and export). The following terminals were chosen for this comparative assessment:

- Export coal terminal at the Port of Nacala, Mozambique (18 MTPA);
- Carrington Coal Terminal at the Port of Newcastle, Australia (25 MTPA);
- Import coal terminal at the Port of Rotterdam, Netherlands (60 MTPA);
- Iron Ore Terminal at the Port of Saldanha, South Africa (60 MTPA);
- Richards Bay Coal Terminal, South Africa (91 MTPA); and
- Kooragang Coal Terminal at the Port of Newcastle, Australia (120 MTPA);

5.2 Comparison approach

The following approach has been adopted for the comparison of Concept Options from the new conceptual design tool to the terminals' reality:

- Each of the terminals' actual parameters (termed as 'Real Parameters') (such as the throughput capacity, number of berths, number of shiploaders/unloaders, length of stockyard, width of stockyard etc) was adopted as inputs into the model.
- The model's outputs were then assessed against the provided inputs (e.g. the output quay length was compared to the actual quay length).
- The range of feasible Concept Options and Sub-Concept Options was then assessed, in the context of the Real Parameters.
- A single Concept Option was then chosen, and the outputs of the new conceptual design tool were recorded.

- The outputs of the new conceptual design tool were then reviewed, and a selected number of output design parameters were chosen for comparison with the Real Parameters. These are shown in Table 5-1 and the comparisons for each of the terminals are summarized in the sections that follow.

Table 5-1: Comparative parameters

New conceptual design tool module	Unit	Output parameter
Module 1 – Seaside handling and configuration	*Number*	Berths
	Metres	Quay length
	Number	Total shiploaders
	Tonnes per hour	Capacity per shiploader
Module 2 – Landside handling and configuration	*Number*	Total landside handlers
	Tonnes per hour	Capacity per landside handler
Module 3 – Stockyard handling and configuration	*Number*	Stockpile lanes
	Metres	Width per stockpile lane
	Metres	Length of stockyard
	Metres	Width of stockyard
	Square metres	Area of stockyard
	Number	Total stockyard handlers
	Tonnes per hour	Capacity per stockyard handler

5.3 Results of comparisons

The Concept Options generated by the conceptual design tool for each of the selected terminals was assessed in light of the terminal characteristics. A single Concept Option was chosen, and the output parameters of this Concept Option were then compared to the respective Real Parameters of the each of the terminals.

The results of this comparison are included in Table 5-2 and illustrated in Figure 5-1. It should be noted that a difference of 0% does not indicate that the new conceptual design tool provided the exact output(s) to match a terminal's Real Parameter(s) but indicates that the terminals Real Parameter(s) were included in the Concept Options generated by the new conceptual design tool. Further, differences of 40% and 100% (especially in the case of the stockyard area) indicate that the terminal's Real Parameter(s) are much larger, such as the case of the Saldanha Iron Ore Terminal, where the current stockyard is much larger than the new conceptual design tool's calculated storage area requirement

For example, in the case of Kooragang Coal Terminal which has five berths and three ship loaders, feasible concept options included berth layouts of as high as seven berths or as low as three berths with varied numbers of shiploaders for each of the respective berth and shiploader-configurations and included (as a Concept Option) the berth and shiploader-configuration found at Kooragang Coal Terminal.

Table 5-2: Comparison of selected outputs from the new conceptual design tool to selected terminal characteristics

Output parameter	Unit	Kooragang Coal Terminal	Richards Bay Coal Terminal	Iron ore Terminal, Saldanha	EMO Terminal, Rotterdam	Carrington Coal Terminal	Nacala Coal Terminal
MODULE 1 – SEASIDE HANDLING AND CONFIGURATION							
Quay length	*Metres*	12%	-15%	1%	34%	3%	-16%
Total shiploaders	*Number*	0%	0%	0%	50%	0%	0%
Capacity per shiploader	*Tonnes per hour*	4%	-27%	3%	0%	0%	0%
MODULE 2 – LANDSIDE HANDLING AND CONFIGURATION							
Total landside handlers	*Number*	0%	-20%	0%	0%	0%	0%
Capacity per landside handler	*Tonnes per hour*	-27%	0%	-23%	0%	0%	0%
MODULE 3 – STOCKYARD HANDLING AND CONFIGURATION							
Width per stockpile lane	Metres	0%	0%	10%	0%	0%	0%
Length of stockyard	Metres	-11%	-9%	79%	69%	-22%	25%
Width of stockyard	Metres	-5%	-7%	12%	-18%	-4%	-19%
Area of stockyard	Square metres	-15%	-16%	100%	40%	-26%	1%
Total stockyard handlers	Number	-33%	-30%	0%	17%	0%	0%
Capacity per stockyard handler	Tonnes per hour	0%	-20%	0%	0%	0%	0%

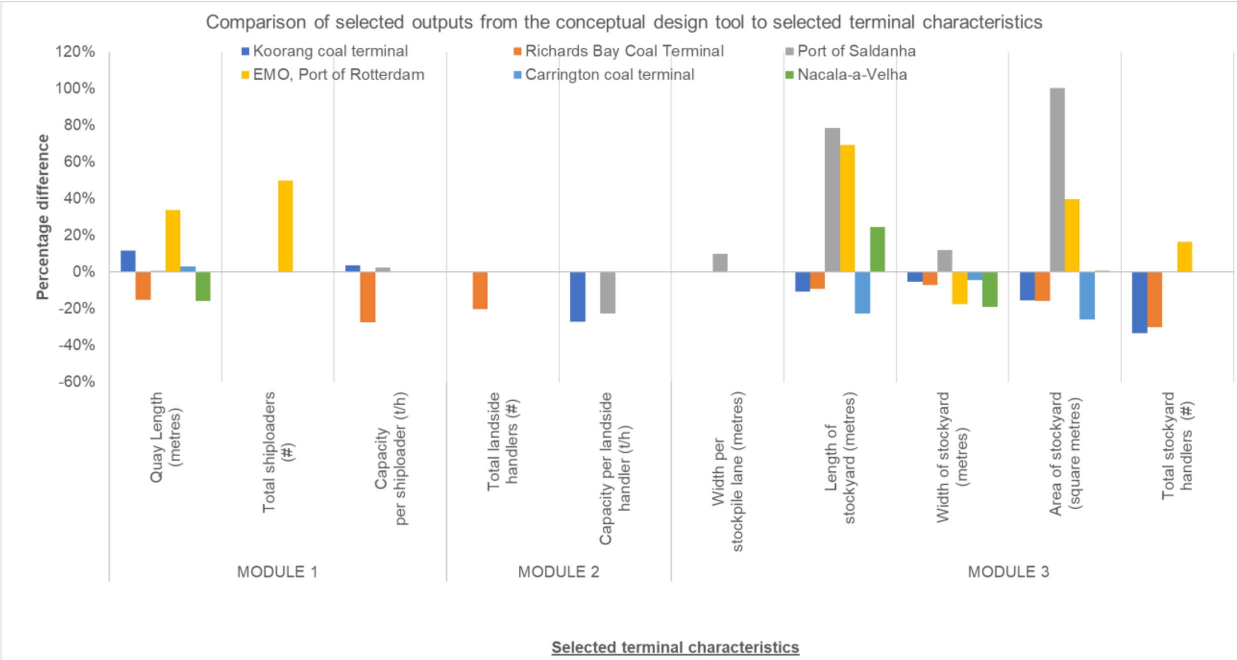

Figure 5-1: Comparison of selected outputs from the new conceptual design tool to selected terminal characteristics

5.4 Analysis of comparative results

Overview

A range of iron ore and coal import and export terminals with throughputs varying from 120MTPA to 18MTPA were chosen to assess the functionality, accuracy and flexibility of the new conceptual design tool. Six terminals located in various locations in South Africa, Mozambique, Australia and Netherlands were selected for comparative purposes. The generated Concept Options for each of the terminals in respect of the seaside, landside and stockyard handling and configuration may be found in Appendix A.

Limitations of comparison approach

The aim of the new conceptual design tool is not to provide single or deterministic output parameters that set in stone the absolute layout of a dry bulk terminal, but rather the aim is to provide a range of output options that project developer(s) may consider. Concept Options generated by the new conceptual design tool may thus be considered by project developer(s) /user(s) as a range of (feasible) options for further consideration and evaluation during the detailed design phases. Any one of the Concept Options that may be chosen by project developer(s) / user(s) is thus an informed decision based on the review of a number of feasible output options. Given that all terminals selected for comparison in this section (Section 5) are operational terminals, it was unlikely that the throughput capacities used and the resultant berth layouts and configurations would be deemed to be unfeasible by the new conceptual design tool.

An example of this may be seen in the comparison undertaken for Richards Bay Coal Terminal (RBCT), as shown in Figure 5-2, where the various berth layouts based on varying individual shiploader capacities is illustrated (noting that the number of shiploaders is fixed to four, as is actually the case at RBCT). Figure 5-2 illustrates that the current layout at RBCT of 6 berths and four shiploaders at a mean average capacity of 9,750 tonnes/hour (illustrated by means of the red cross) results in an overall berth utilization of well below 60%, which is the widely accepted benchmark for optimum operations. It is further illustrated that in the unlikely event of the available number of berths decreasing to four, corresponding RBCT management may be required to increase the capacity per shiploader (all other factors being equal and noting the limitations of the new conceptual design tool stated in Section 3) to circa 15,000 tonnes/hour.

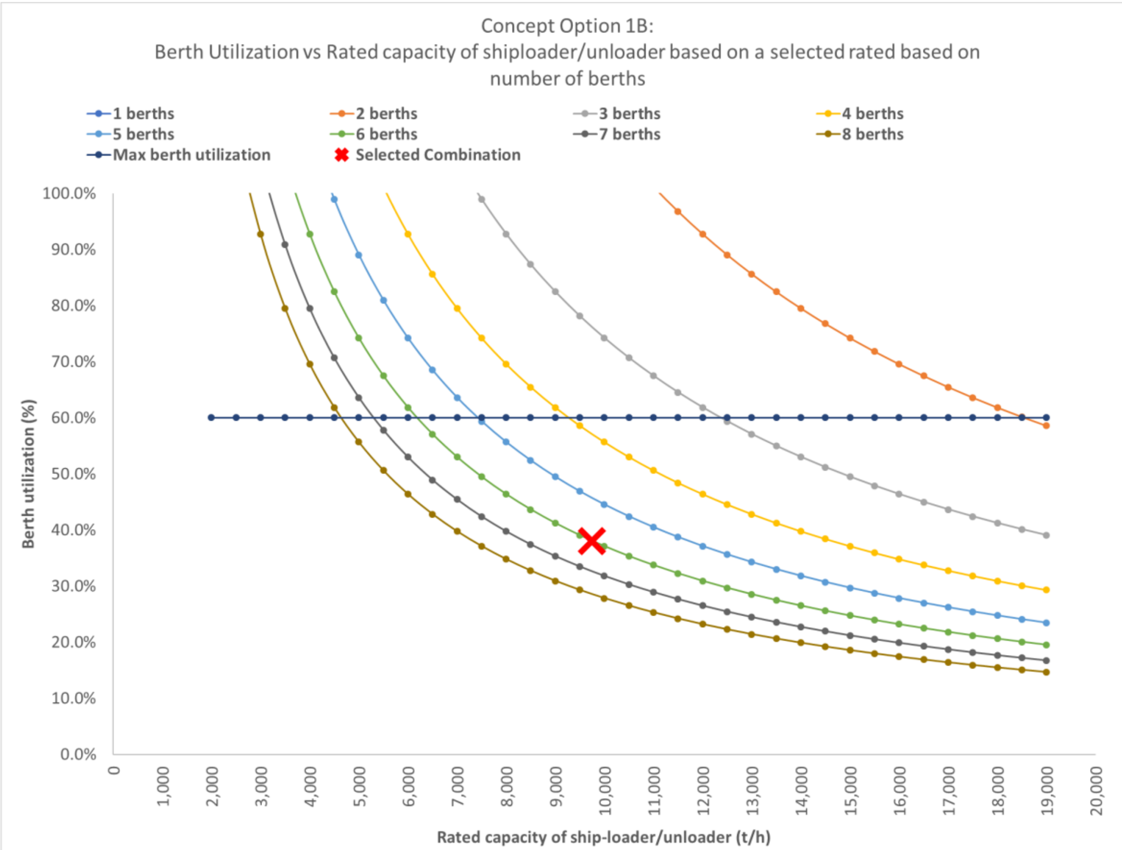

Figure 5-2: Richards Bay Coal Terminal - Berth and shiploader Concept Options

However, in order for a comparative assessment to be undertaken, a single Concept Option had to be chosen from the provided range of Concept Options shown in Figure 5-2. That is, in the case of the seaside handling configuration for RBCT, six berths with a total of four shiploaders at an average capacity of 9,750t/h is the chosen Concept Option).

In the context of the above and considering the overall aim of the new conceptual design tool, several typical output design parameters do not vary between the outputs of the new conceptual design tool and that of reality. Examples of this include the number of berths or the number of stockpile lanes (as the chosen Concept Option has the same number of berths or stockpile lanes as the actual terminal). However, variance can be observed in the output parameters that are dependent on the calculations and assumptions incorporated into the new conceptual design tool. Examples of these outputs include the length of the quay, the length, width and area of the stockyard and the number of stockyard handlers and given that the sample size of the terminals selected for the comparison (six) is small, a mean average or trendline assessment of results cannot be undertaken, as variances in even one value would unfairly skew the results.

Specific analysis

Selected output variables were chosen for specific analysis, keeping in mind that these output variables are not the macro-level parameters which may be of more importance for consideration by project developers (such as number of berths and shiploaders, number of stockpile lanes and the number and capacity of landside handlers).

However, it is noted that for larger export terminals (such as Kooragang and RBCT), the new conceptual design tool underestimated the length of the stockyard by up to 11%. This may be due to the new conceptual design tool extrapolating the number of individual stockpiles in each of the lanes or underestimating the heights of the stockpiles. In addition, it appears that the new conceptual design tool consistently underestimated the total width of the stockyard by between 5%-19%, which may be attributed to the new conceptual design tool underestimating the widths of individual stockpiles or the spatial allowances for internal roads and stacker-reclaimer rail gauges.

The new conceptual design tool also overestimated the quay length for four out of the six terminals, due to both the flexibility factor and the average vessel size (which is a product of the estimate of the vessel mix that was required to be catered for).

6 Conclusions and recommendations

This section describes the conclusions and makes several recommendations for further study based on the findings of this Thesis. Section 6.1 presents a synopsis of the study and outlines the primary conclusions, while recommendations for further study are described in section 6.2.

6.1 Conclusions

6.1.1 Overview

Dry bulk terminals are a critical link in the overall mine-to-market transport chain for commodities that keep the world's economy ticking over. The development of greenfield dry bulk terminals and the expansion and refurbishment of brownfield dry bulk terminals are typically major engineering projects spanning several years and multiple engineering stages.

The literature review undertaken described the varying types of required infrastructure, and terminal equipment and the variables that may need to be considered in respect of the conceptual design of a dry bulk terminal. The literature review also provided a review of simulation-integrated computer methods and previously conceptual design tools previously developed by others, and further detailed salient characteristics of a selected number of dry bulk terminals around the world, so as to provide the basis of the case studies to be undertaken with the proposed new conceptual design tool.

The objective of the study was to develop a new conceptual design tool, based on literature to rapidly establish, based on varying inputs, a wide range of preliminary spatial and technical viable output parameters to assist consultants, advisors, developers, financiers, governments, and port authorities during the conceptual design phase.

The new conceptual design tool developed by the Author provided a range of viable outputs (based on the user's inputted restrictions), termed as **Concept Options** for each component of a dry bulk terminal. On average, a total of 240 Concept and Sub-Concept Options were generated for each component of the new conceptual design tool, with components being:

- The seaside handling and configuration component (i.e. the inflow area in the case of an import terminal, or the outflow area in the case of an export terminal);
- The landside handling and configuration component (i.e. the outflow area in the case of an import terminal, or the inflow area in the case of an export terminal); and
- The stockyard handling and configuration component (i.e. buffer, material storage and material blending area for all dry bulk terminals);

The new conceptual design tool requires users to provide certain critical inputs (such as the throughput capacity, the stockyard capacity) as well set certain limitations or restrictions (such as the maximum berth of handler utilization or the maximum stockyard area) based on the user's project specificities.

6.1.2 Investigation into selected dry bulk terminals around the world

A number of iron ore and coal dry bulk terminals from various locations around the world were investigated so as to review their salient features and provide a basis for comparison to the results of the new conceptual design tool. Thirteen terminals from Australia, Brazil, South Africa, Mozambique and Europe were researched and seven of these terminals were compared using the new conceptual design tool. A summary of the researched terminals, illustrating selected salient features is exhibited in Table 6-1.

Table 6-1: Summary of researched dry bulk terminals

Terminal name	Kooragang Coal Terminal	Ponta da Madeira	Richards Bay Coal Terminal	Port of Saldanha	EMO, Port of Rotterdam	Carrington Coal Terminal	Nacala-a-Velha	Hansaport, Hamburg	Ridley coal terminal
Location	**Australia**	**Brazil**	**South Africa**	**South Africa**	**Netherlands**	**Australia**	**Mozambique**	**Germany**	**Canada**
Primary commodity	Coal	Iron Ore	Coal	Iron Ore	Coal	Coal	Coal	Coal	Coal
Throughput capacity (MTPA)	120	190	91	60	60	25	18	18	16
Number of berths	5	5	6	2	4	2	1	4	2
Quay Length (metres)	1,396	1,915	2,200	630	1,365	615	385	760	320
Number of loaders/unloaders per berth	1	2	1	1	1	1	2	1	1
Total number of loaders/unloaders	3	8	4	2	4	2	2	4	2
Storage capacity (million tonnes)	4	14	8	5	10	1	1	3	1
Number of stockpile lanes	4	17	7	8	7	4	3	8	4
Total width of stockyard	310	1,300	650	560	690	230	200	350	360
Number of stacker reclaimers	6	19	10	4	6	4	2	5	3

6.1.3 New conceptual design tool Concept Options

When comparing the range of Concept Options from the new conceptual design tool to the proposed design parameters of an export dry bulk terminal project (with an annual throughput of 240MTPA) that is still in feasibility stage, the following was observed:

- The new conceptual design tool provided a range of Concept Options in terms of the number of berths and the shiploader configuration (i.e. the number of shiploaders per berth). These included, *inter alia*:
  - 4 shiploaders, each with a capacity of 13,000t/h for eight berths, with a resultant berth utilization of circa 75%; and
  - 4 shiploaders, each with a capacity of 18,000t/h for six berths, with a resultant berth utilization of circa 75%.
- The selected Concept Option of 4 shiploaders, each with a capacity of 13,000t/h for eight berths proved to be similar to the proposed design feasibility parameters of 4 shiploaders, each with a capacity of 12,000t/h for eight berths. Further, the resultant quay length of circa 2,500m is roughly 20% more than the proposed quay length from the feasibility study. This may be due to the average vessel size which the model approximates from the inputted vessel mix.
- The viable Concept Options generated for the landside handling and configuration component included the proposed layout and configuration of the feasibility study;
- The results of the stockyard handling component indicate that a combination of 10 -stacker reclaimers may be sufficient, as opposed to the proposed 15 stacker-reclaimer combinations. However, the length of the proposed stockyard is in excess of 2,500m and as such the model only accounts for capacity requirements as opposed to the practical requirements of additional stockyard handling equipment.

6.1.4 New conceptual design tool comparison to operating terminals.

A range of iron ore and coal import and export terminals with throughputs varying from 18MTPA to 120MTPA were chosen to assess the functionality, accuracy and flexibility of the new conceptual design tool. Six terminals located in various locations in South Africa, Mozambique, Australia and Netherlands were selected for comparative purposes. The aim of the new conceptual design tool was not to provide single or deterministic output parameters that set in stone the absolute layout of a dry bulk terminal, but rather the aim was to provide a wide range of output options that project developer(s) may consider.

However, for a comparative assessment to be undertaken, a single Concept Option was chosen from the provided range of Concept Options and it was noted that the layout and configuration of all existing terminals selected for comparison was understandably contained within the range of provided Concept Options.

Further, when comparing certain outputs from the new conceptual design tool to those of existing terminals it was found that, amongst others:

- Quay length outputs from the new conceptual design tool varied from the actual quay length, due to the new conceptual design tool approximating the average size of the vessels;
- The lengths, widths and subsequent areas of the stockyards were consistently (except in the case of one terminal) less than the dimensions of stockyards of existing terminals selected for comparison.

6.1.5 Suitability of developed approach

The new conceptual design tool and the findings of the study illustrate that by employing the tool project developers may be able to swiftly generate a range of viable characteristics for a greenfield project or evaluate the impacts of proposed changes to operational projects. The new conceptual design tool has been shown to function for both import and export terminals of varying capacities.

However, the new conceptual design tool requires a user who understands its limitations and is able to assess the generated options in light of a project on the whole, so as to make an informed decision on the selected option.

6.2 Recommendations for future research

The new conceptual design tool is capable of generating multiple Concept Options for a variety of input ranges and only restricted by the input limitations as defined by the user. The new conceptual design tool is able to provide the user with a number of choices for consideration during the detailed design phase but may be enhanced in several aspects.

The following is a non-exhaustive list of areas where the approach adopted in this study must be expanded further:

- The provision of initial capital expenditure requirements for each infrastructure element, to allow for a cost-driven conceptual design optimisation process to be undertaken at a high-level during the conceptual design phase;
- The provision of a simulation-driven approach for each of the new conceptual design tool modules to incorporate the stochastic nature of vessel arrivals, vessel handling, commodity stacking and landside handling and transport;
- The incorporation of the infrastructural requirements (capacities and sizes of conveyors) for the horizontal transport of material from the intake area through the storage area and then to the outtake area;
- The incorporation of the ability to account for a dry bulk terminal with more than one commodity; and

- The incorporation of stockyard lanes with differential lengths and/or widths, as currently only stockyards with stockpile widths that are equal in terms of length and width are included.

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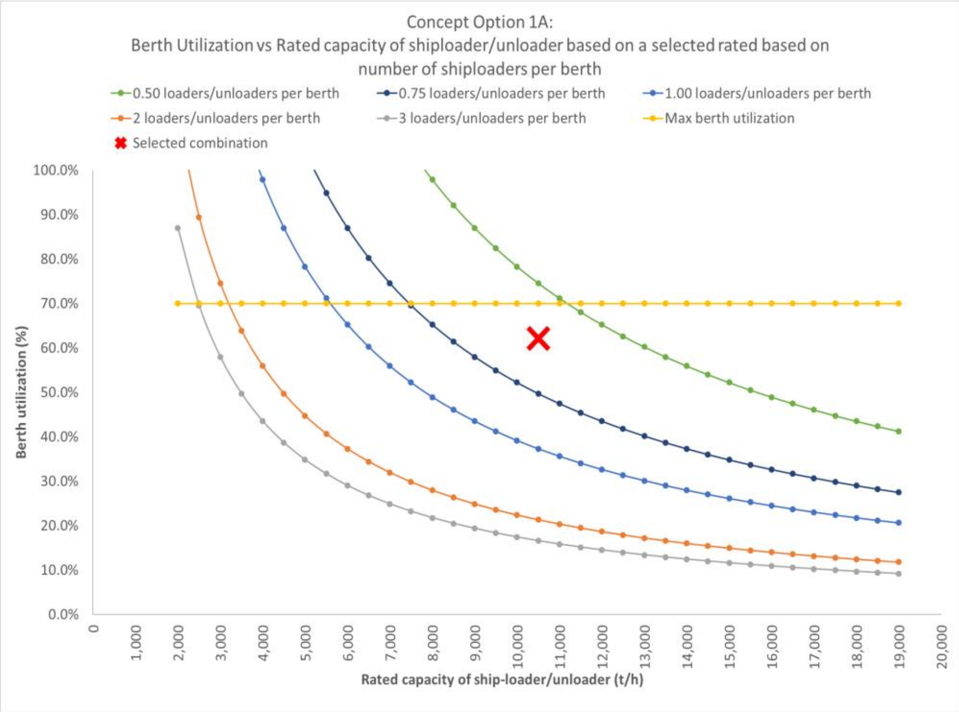
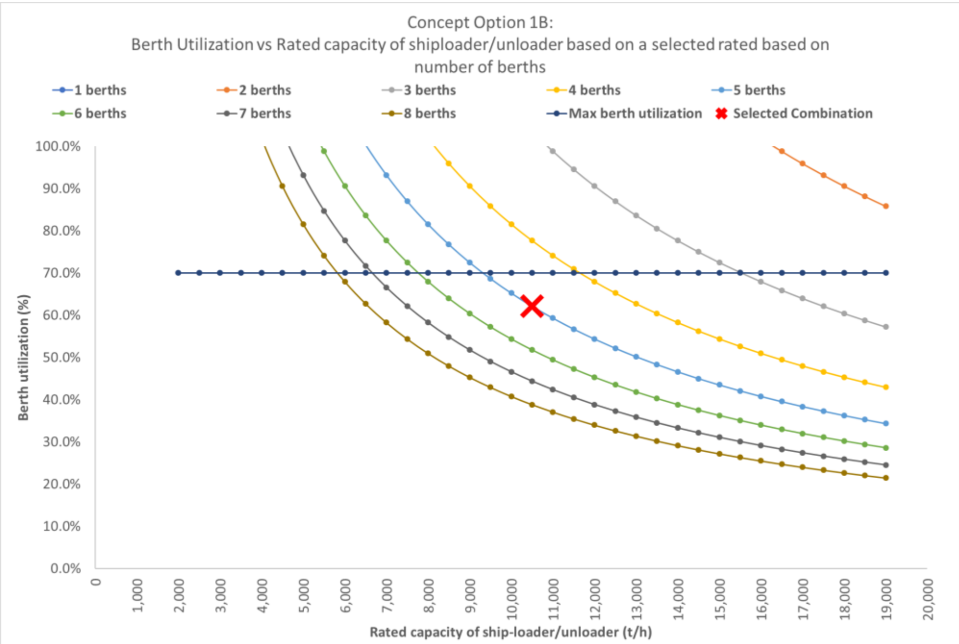
A. Appendix A: Concept Options for existing terminals

A.1 Kooragang Coal Terminal, Port of Newcastle, Australia

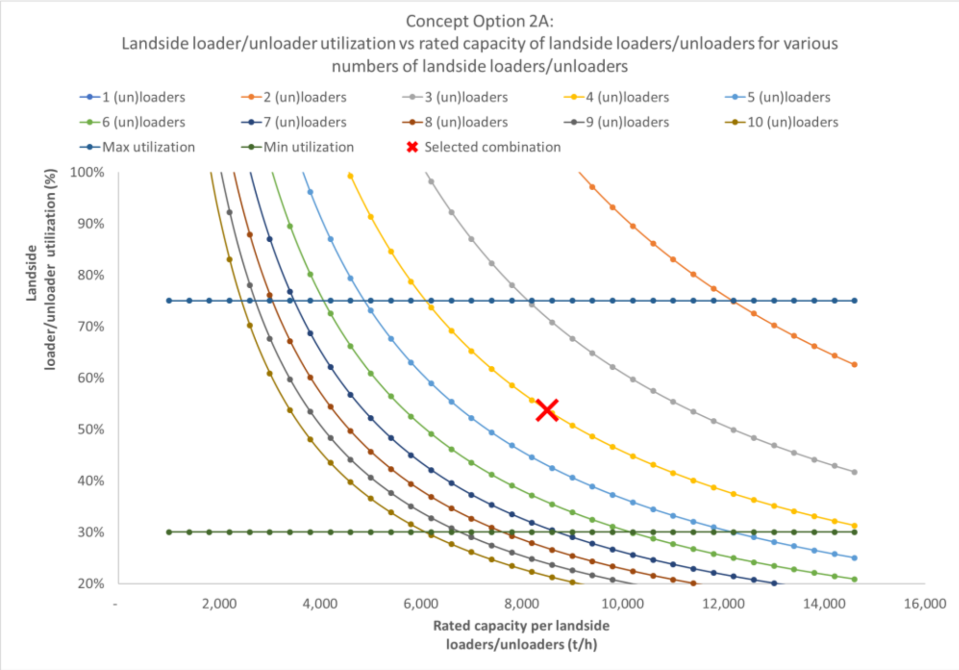
Concept Option 1A – Kooragang Coal Terminal



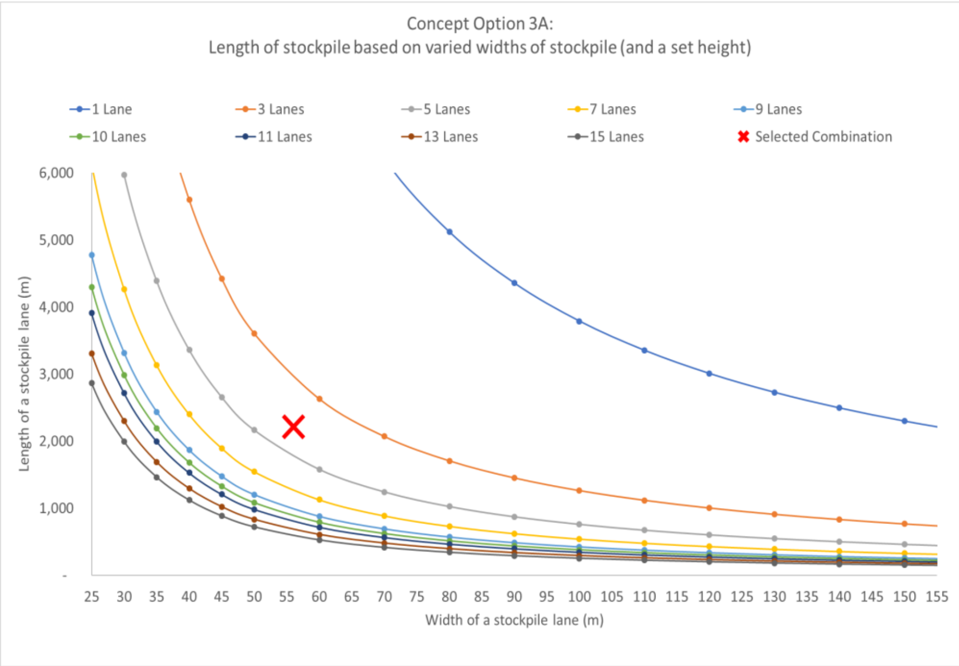
Concept Option 1B – Kooragang Coal Terminal



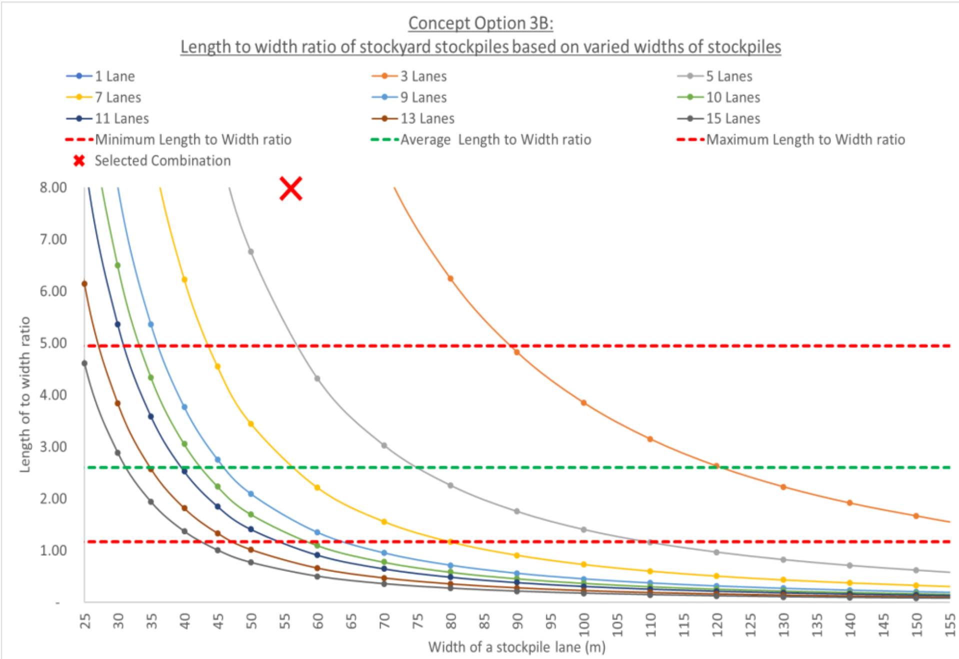
Concept Option 2A – Kooragang Coal Terminal



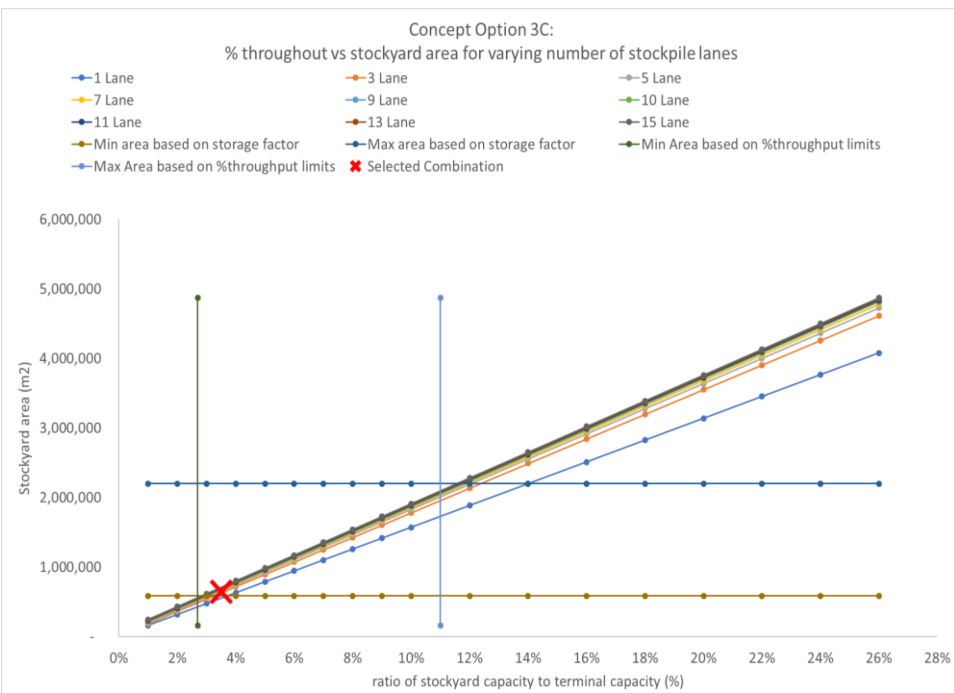
Concept Option 3A – Kooragang Coal Terminal



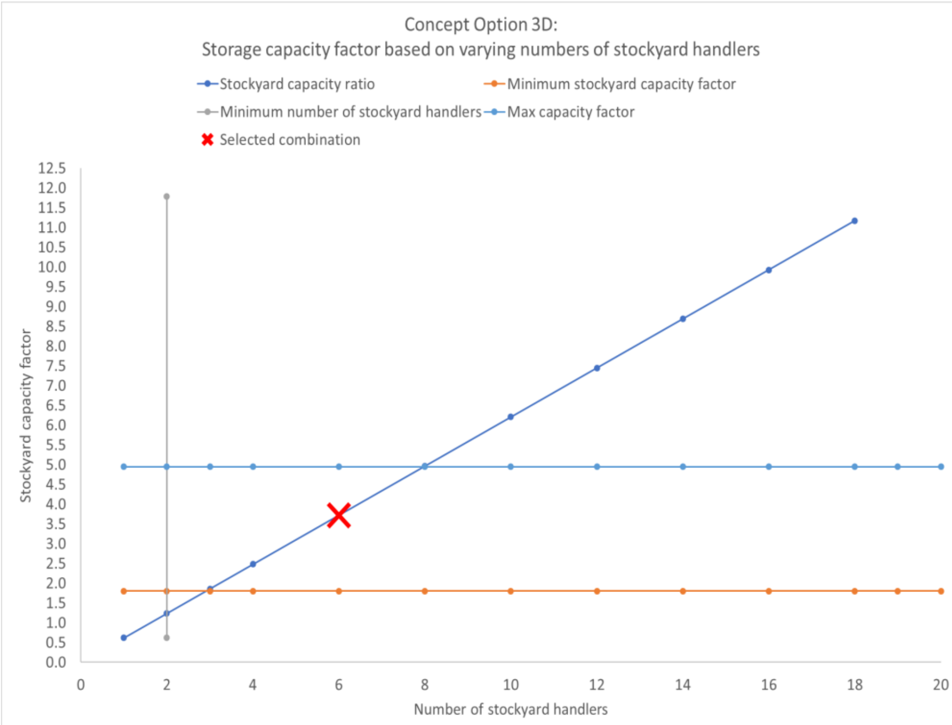
Concept Option 3B – Kooragang Coal Terminal



Concept Option 3C – Kooragang Coal Terminal

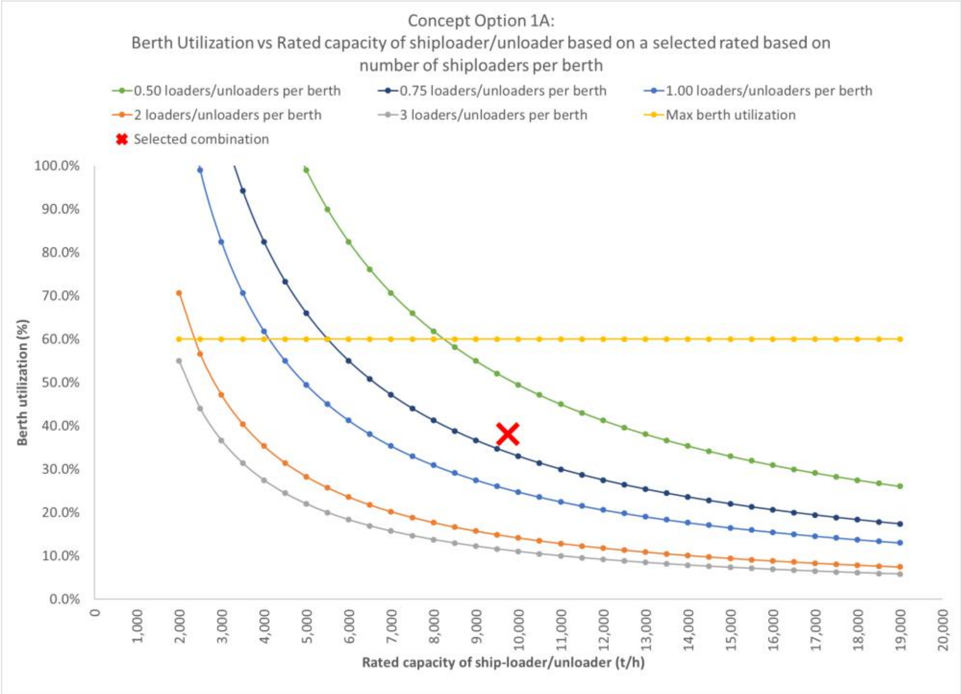


Concept Option 3D – Kooragang Coal Terminal

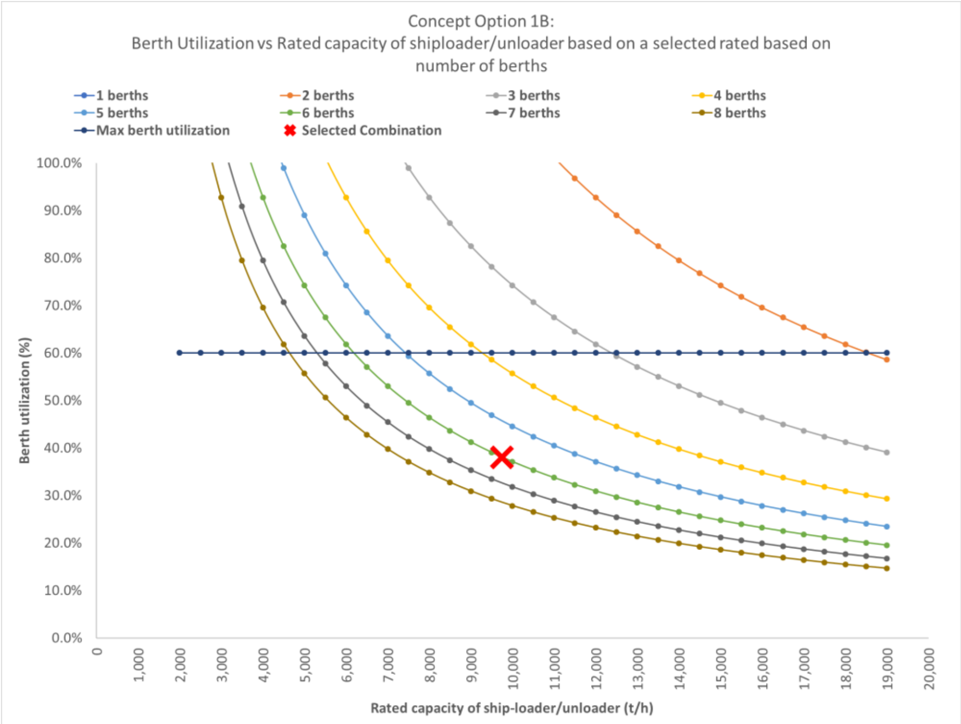


A.2 Richards Bay Coal Terminal, Port of Richards Bay, South Africa

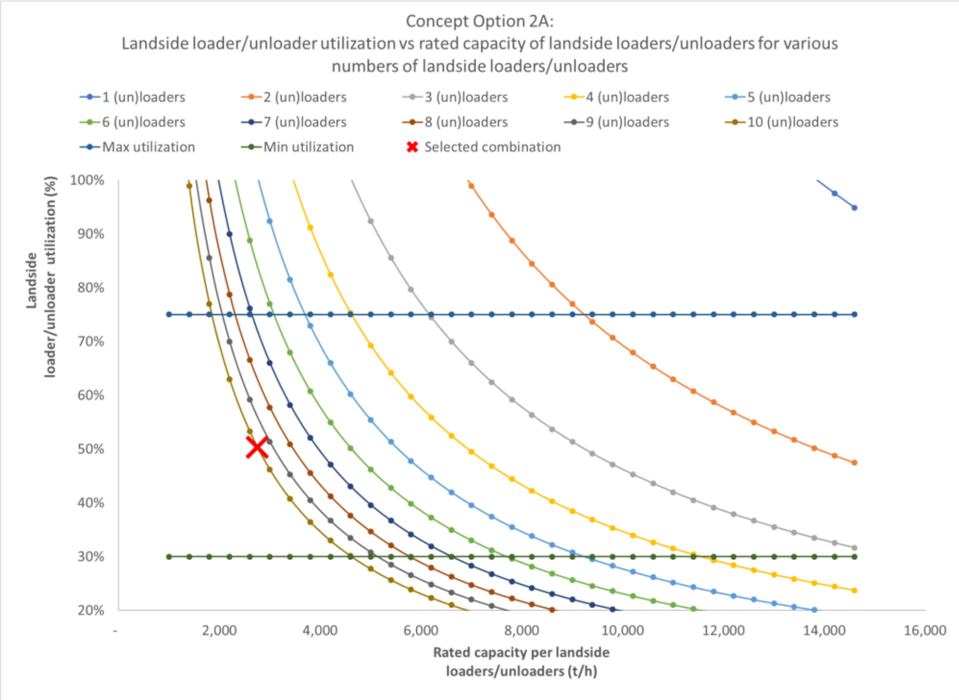
Concept Option 1A – Richards Bay Coal Terminal



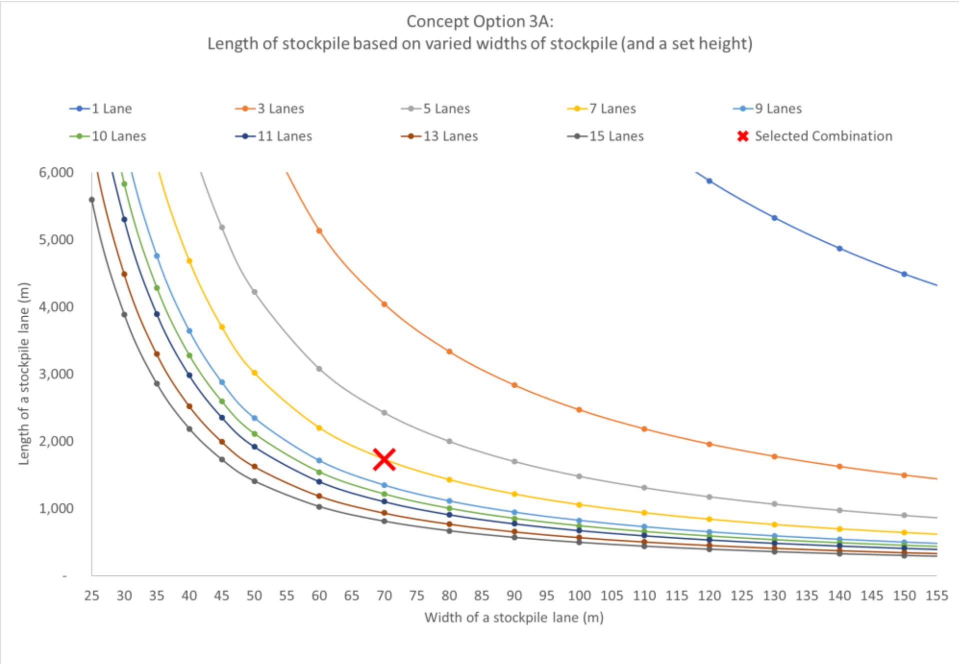
Concept Option 1B – Richards Bay Coal Terminal



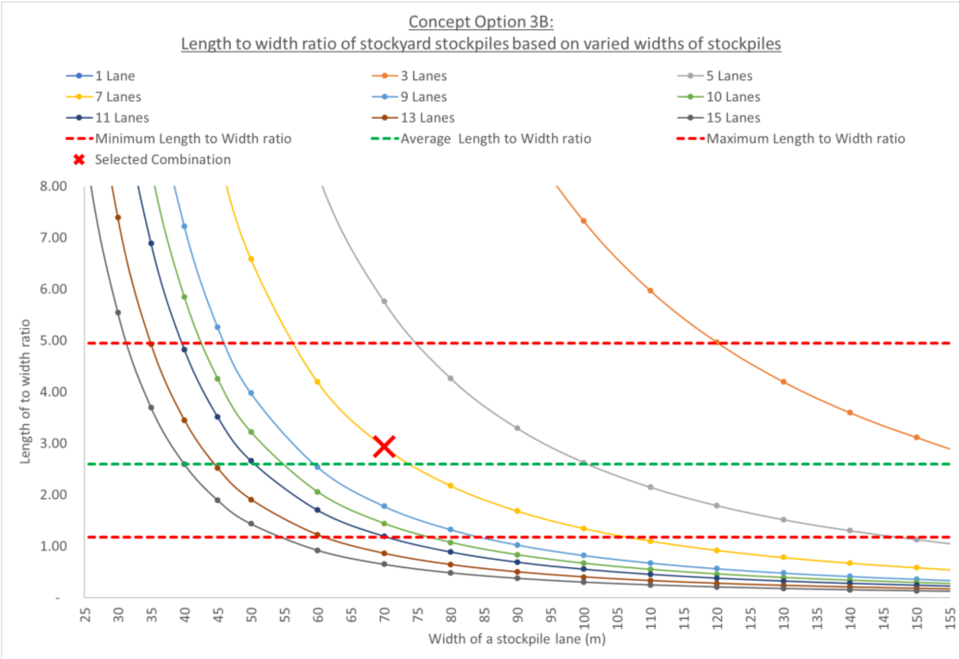
Concept Option 2A – Richards Bay Coal Terminal



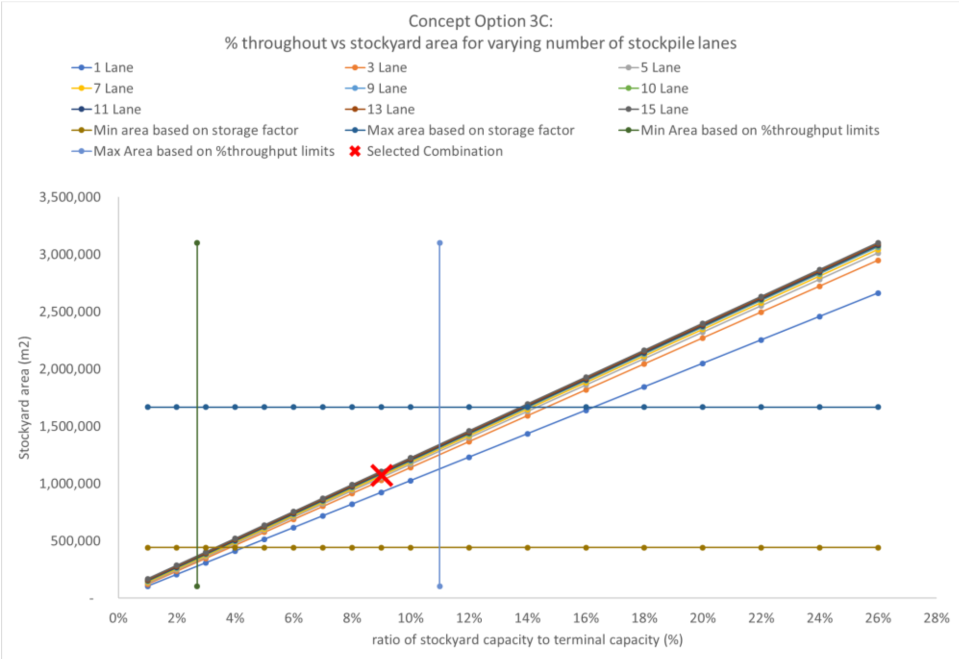
Concept Option 3A – Richards Bay Coal Terminal



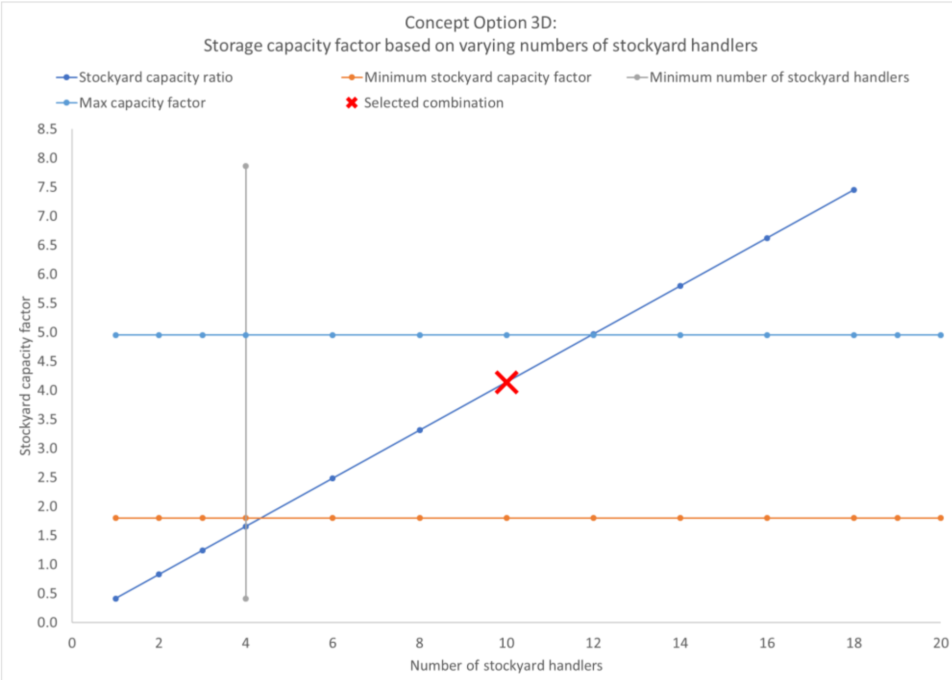
Concept Option 3B – Richards Bay Coal Terminal



Concept Option 3C – Richards Bay Coal Terminal

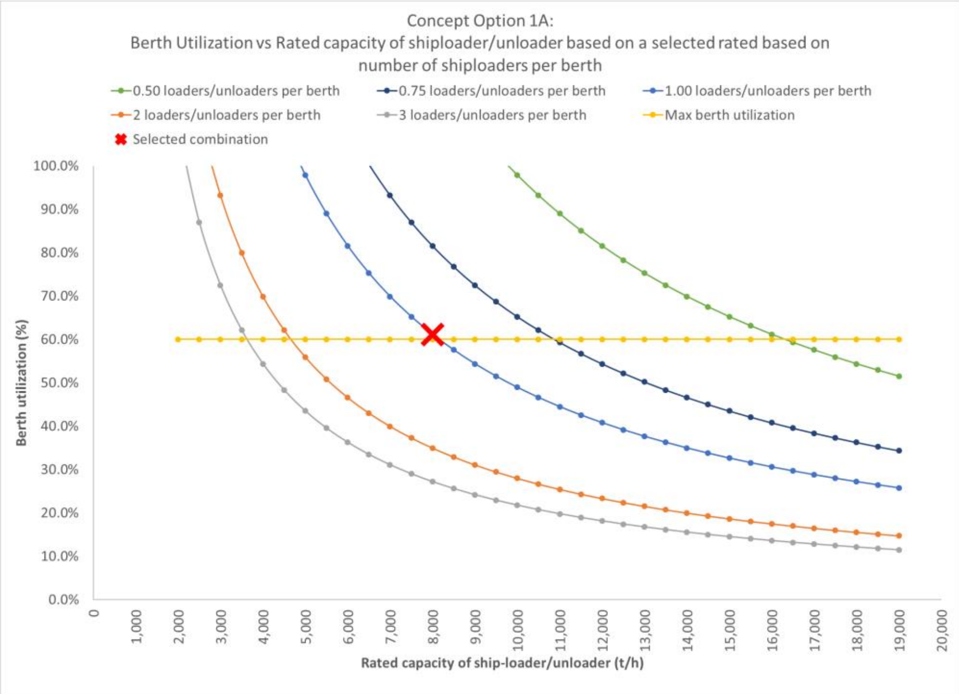


Concept Option 3D – Richards Bay Coal Terminal

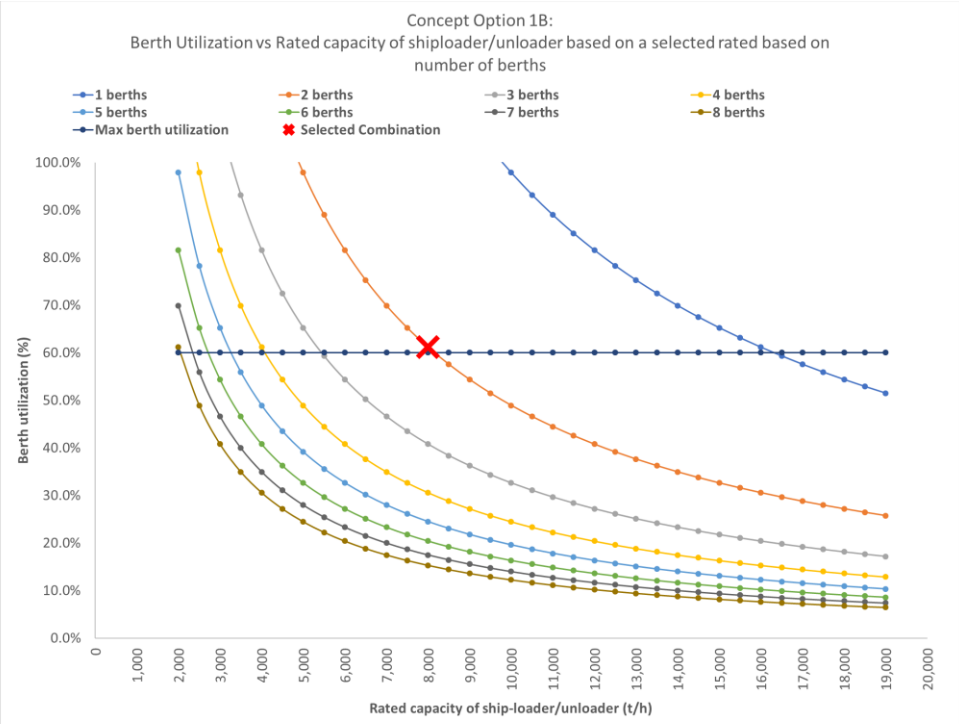


A.3 Iron Ore Terminal, Port of Saldanha, South Africa

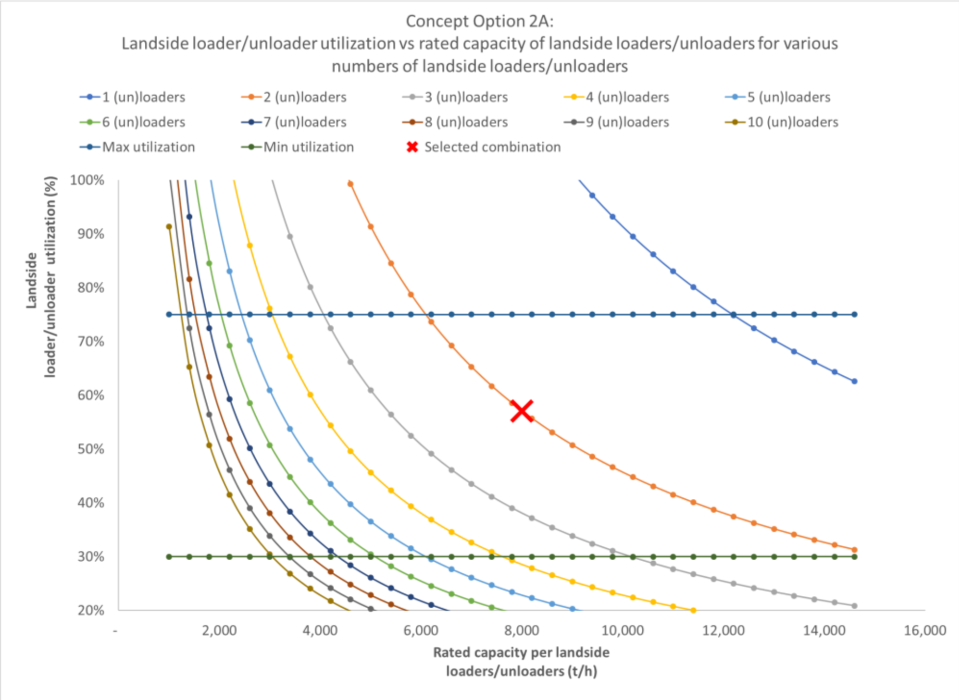
Concept Option 1A – Iron Ore Terminal, Port of Saldanha



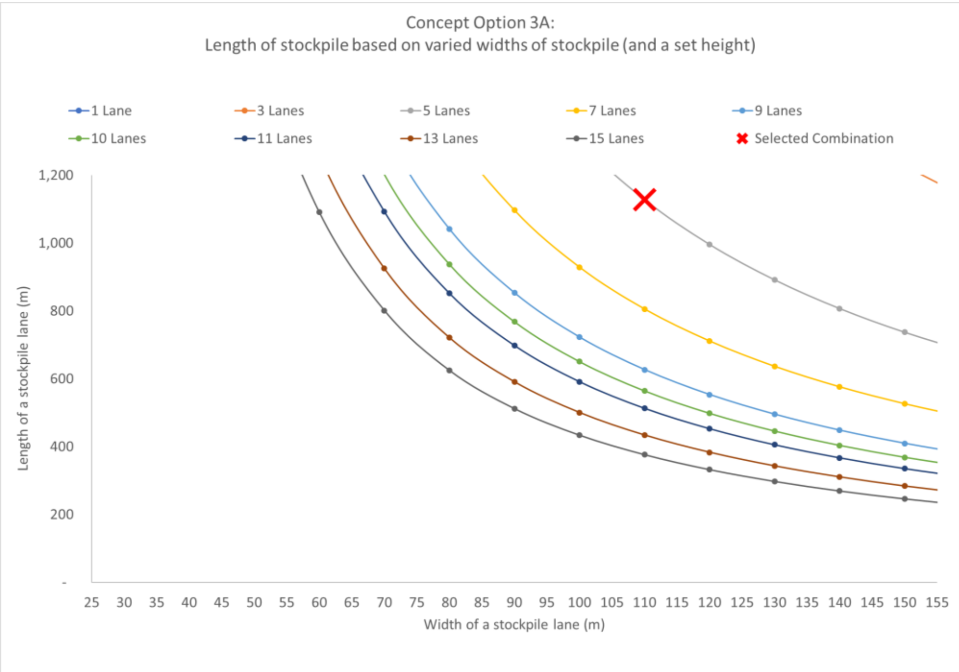
Concept Option 1B – Iron Ore Terminal, Port of Saldanha



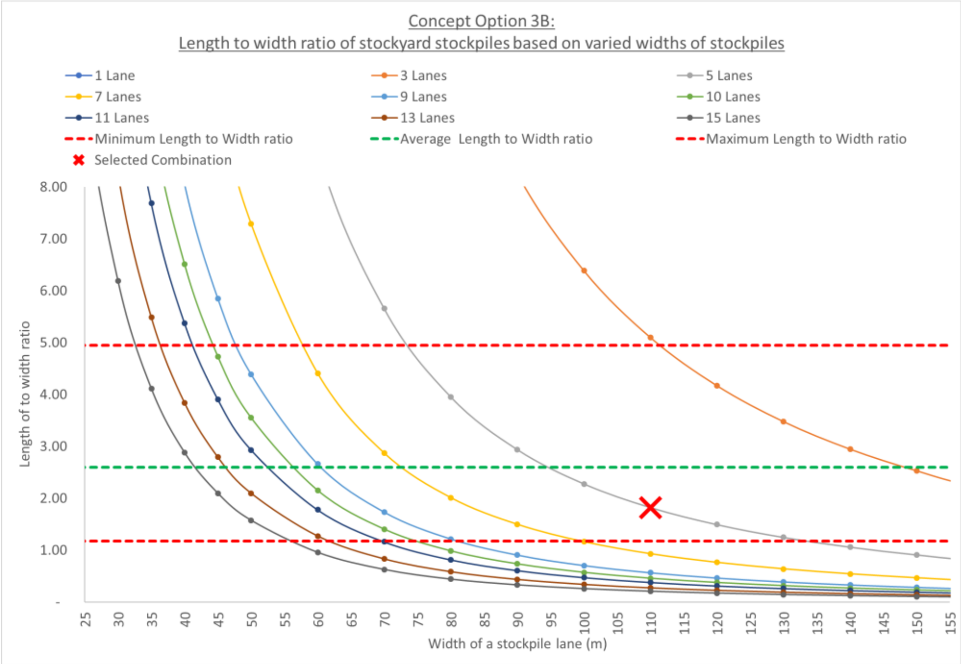
Concept Option 2A – Iron Ore Terminal, Port of Saldanha



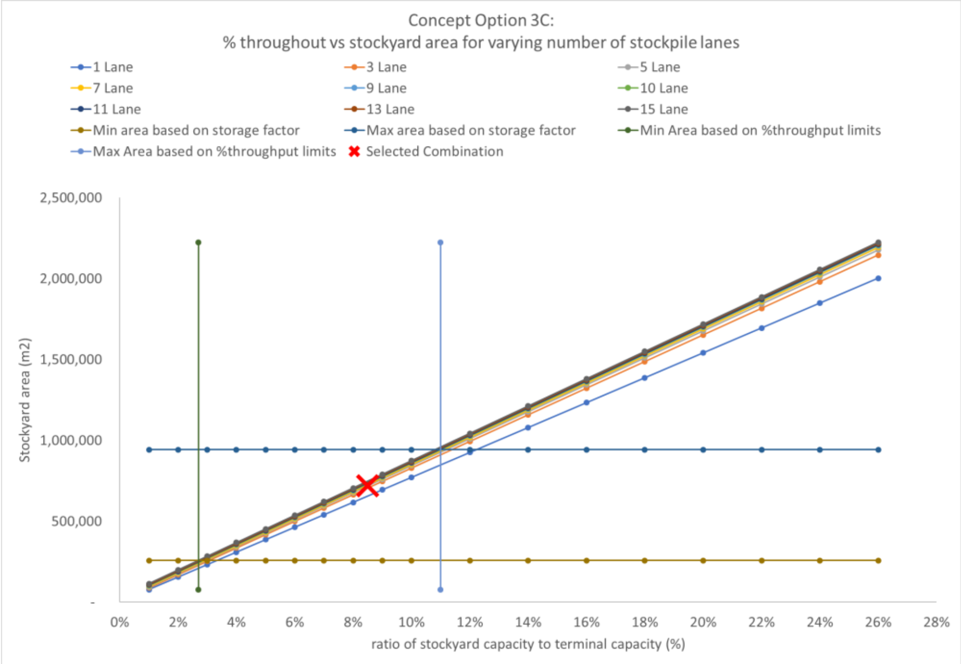
Concept Option 3A – Iron Ore Terminal, Port of Saldanha



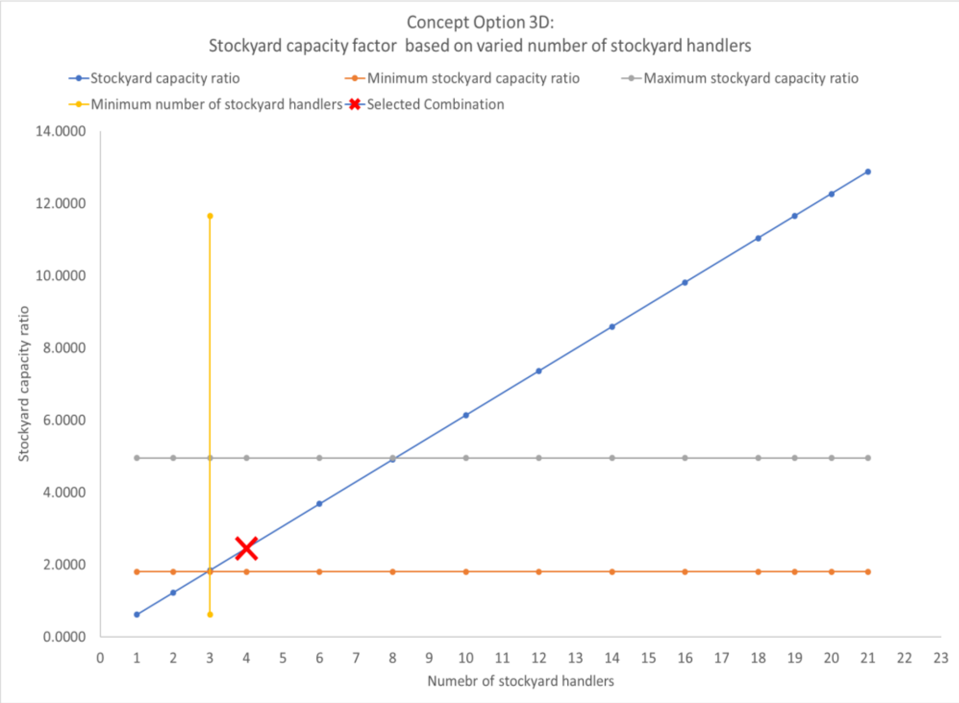
Concept Option 3B – Iron Ore Terminal, Port of Saldanha



Concept Option 3C – Iron Ore Terminal, Port of Saldanha

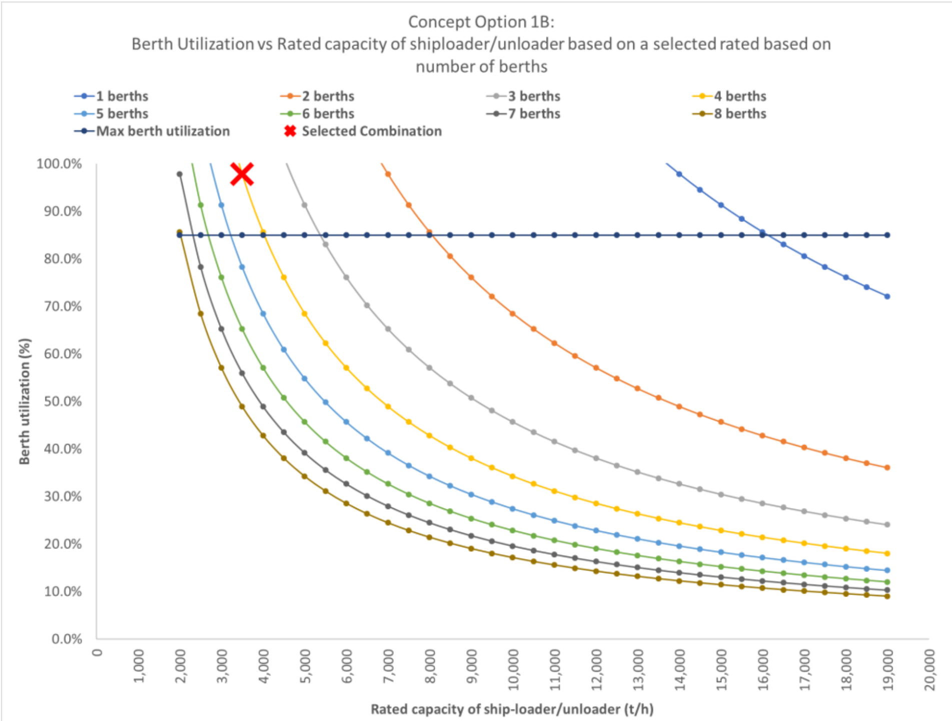


Concept Option 3D – Iron Ore Terminal, Port of Saldanha

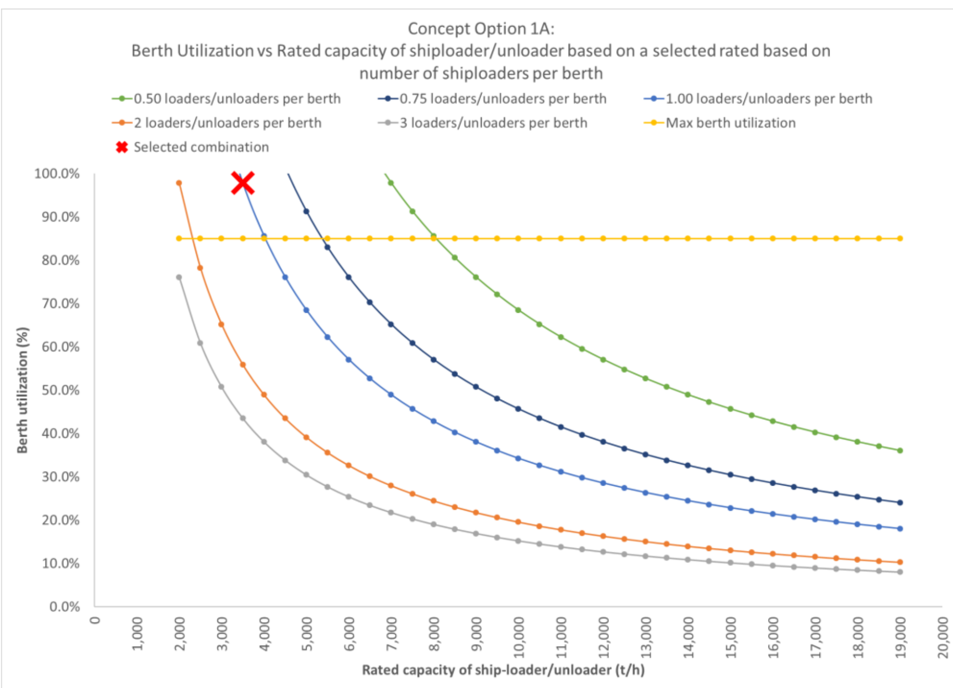


A.4 EMO Terminal, Port of Rotterdam, Netherlands

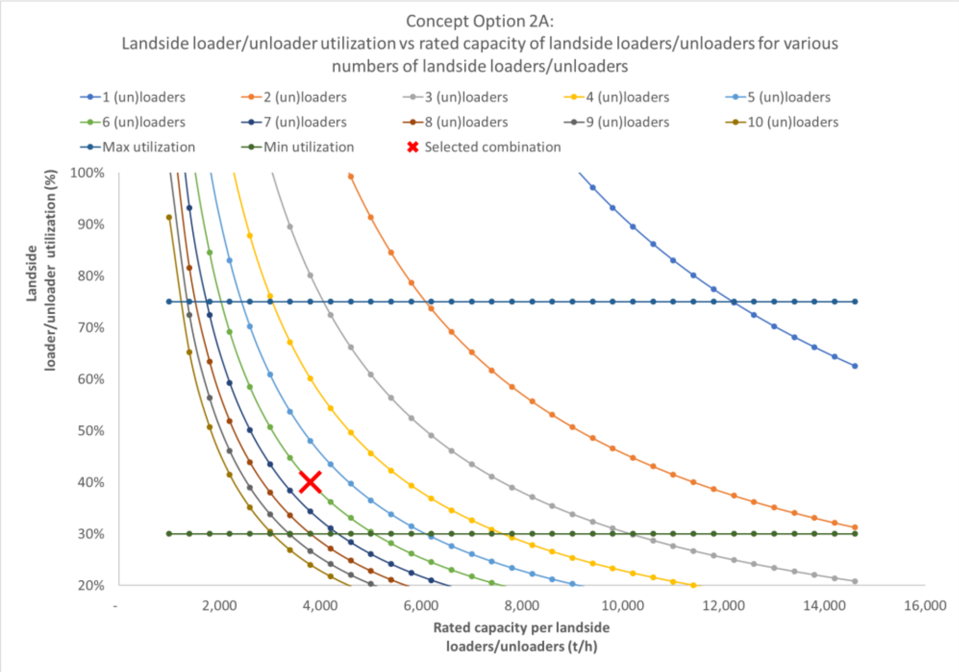
Concept Option 1A – EMO Terminal, Port of Rotterdam



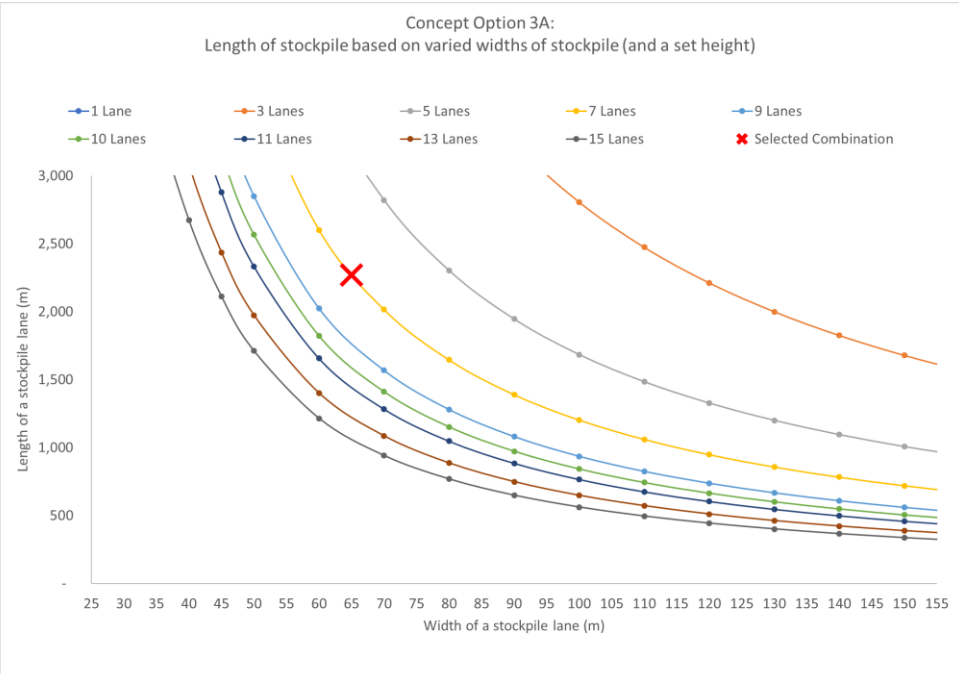
Concept Option 1B – EMO Terminal, Port of Rotterdam



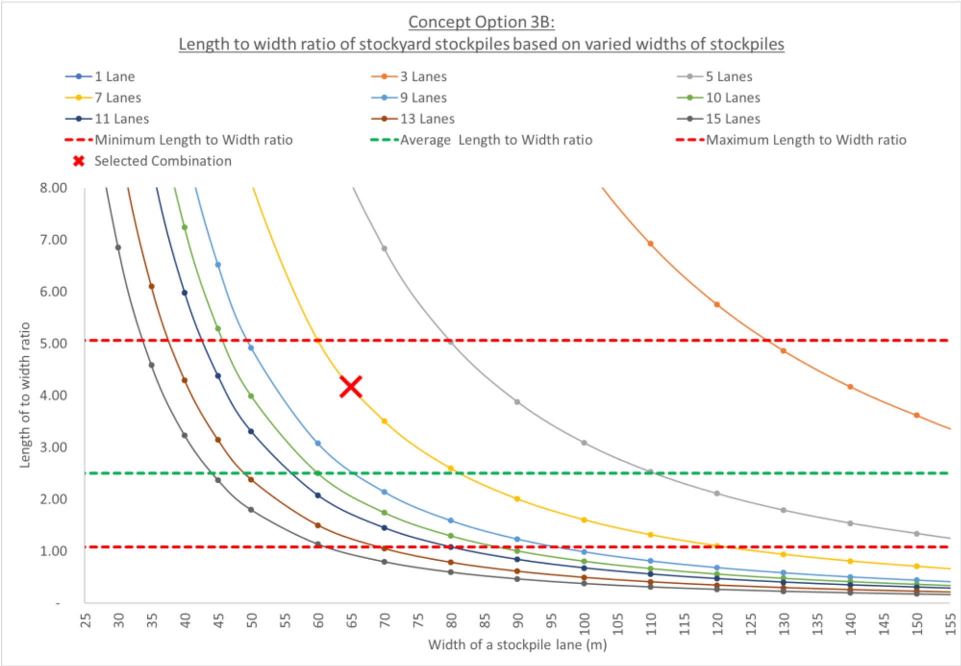
Concept Option 2A – EMO Terminal, Port of Rotterdam



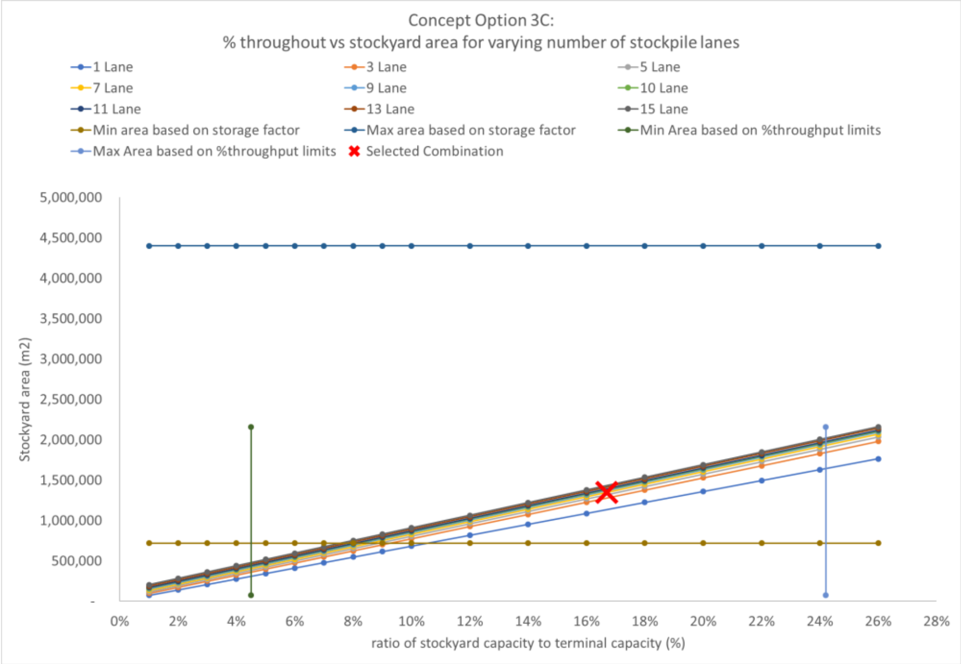
Concept Option 3A – EMO Terminal, Port of Rotterdam



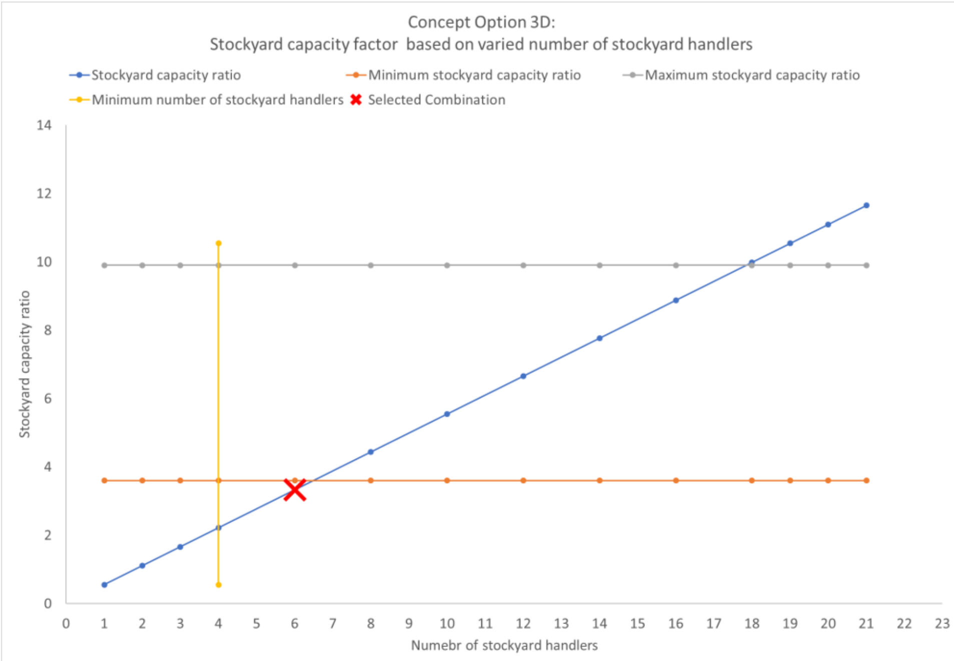
Concept Option 3B – EMO Terminal, Port of Rotterdam



Concept Option 3C – EMO Terminal, Port of Rotterdam

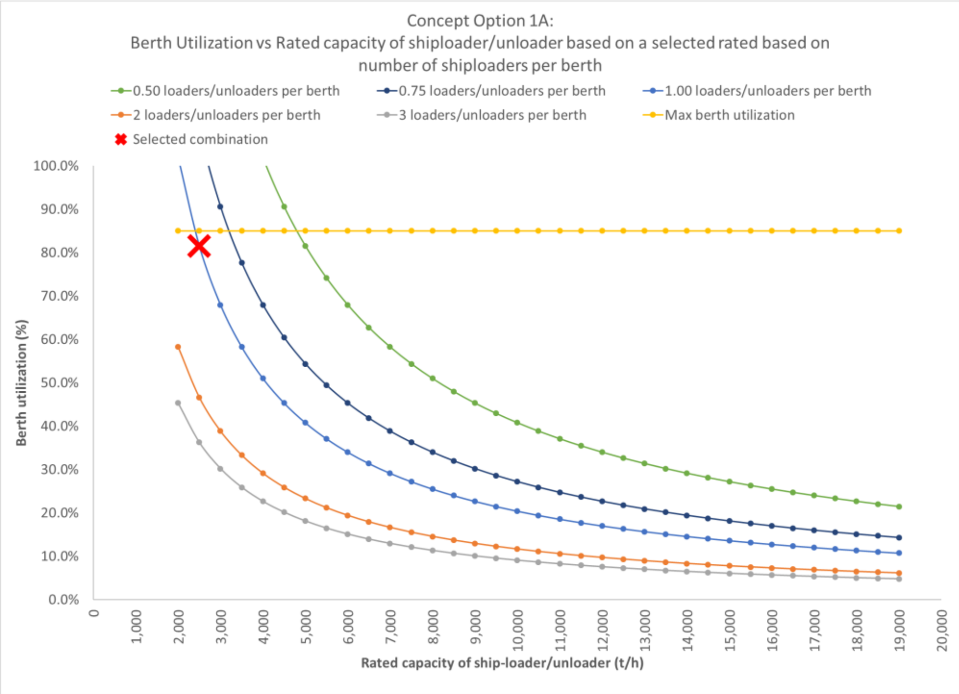


Concept Option 3D – EMO Terminal, Port of Rotterdam

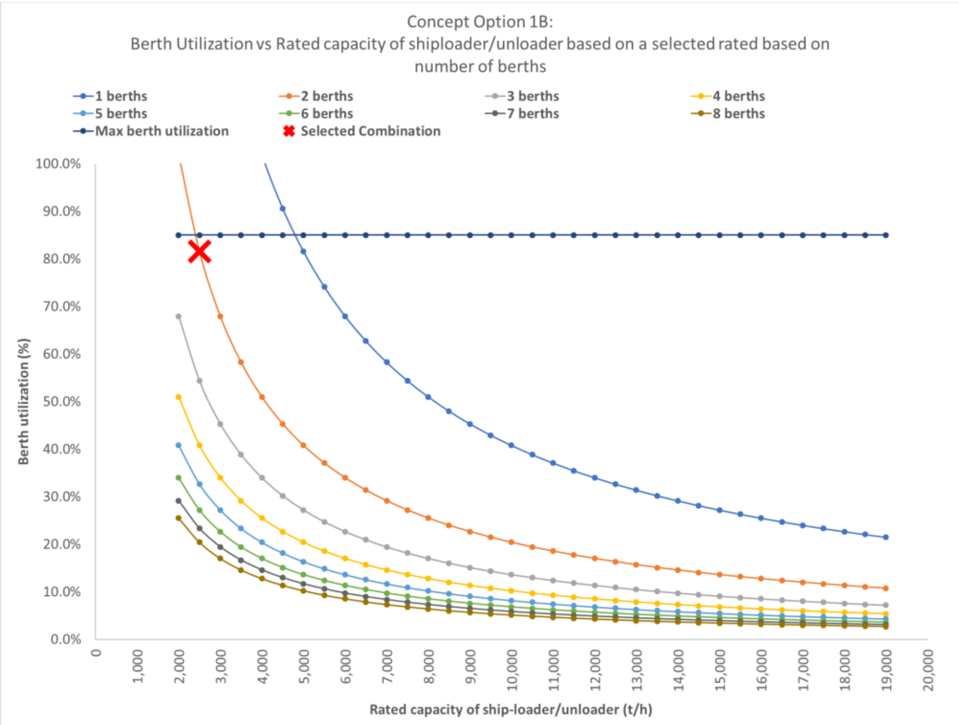


A.5 Carrington Coal Terminal, Port of Newcastle, Australia

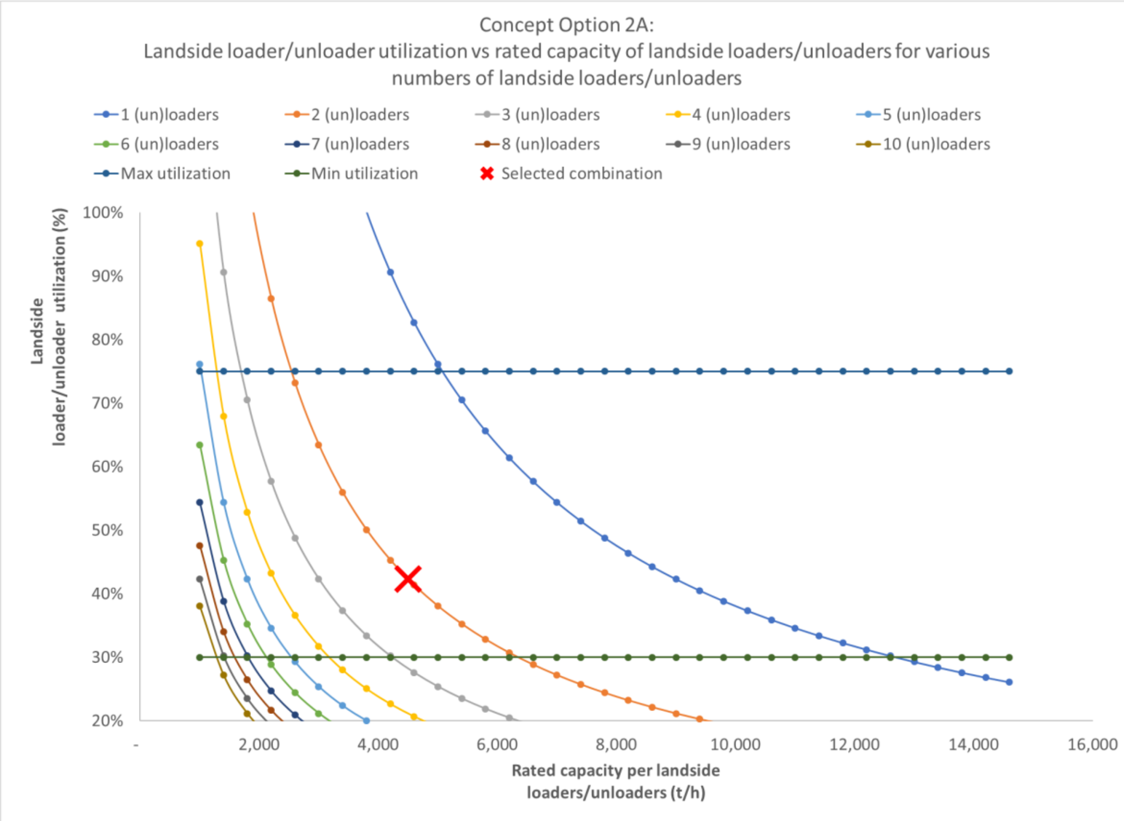
Concept Option 1A – Carrington Coal Terminal



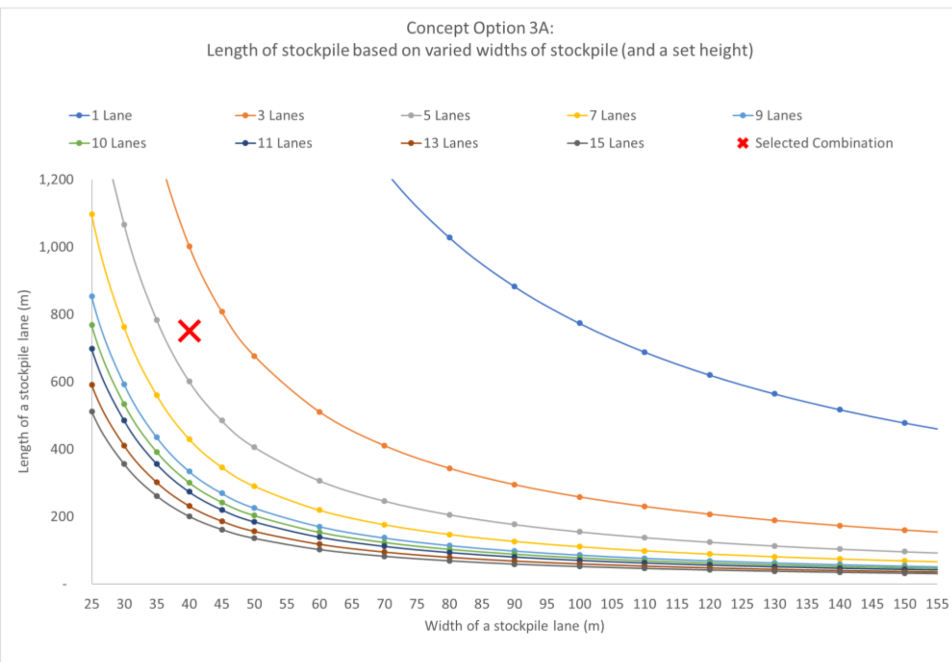
Concept Option 1B – Carrington Coal Terminal



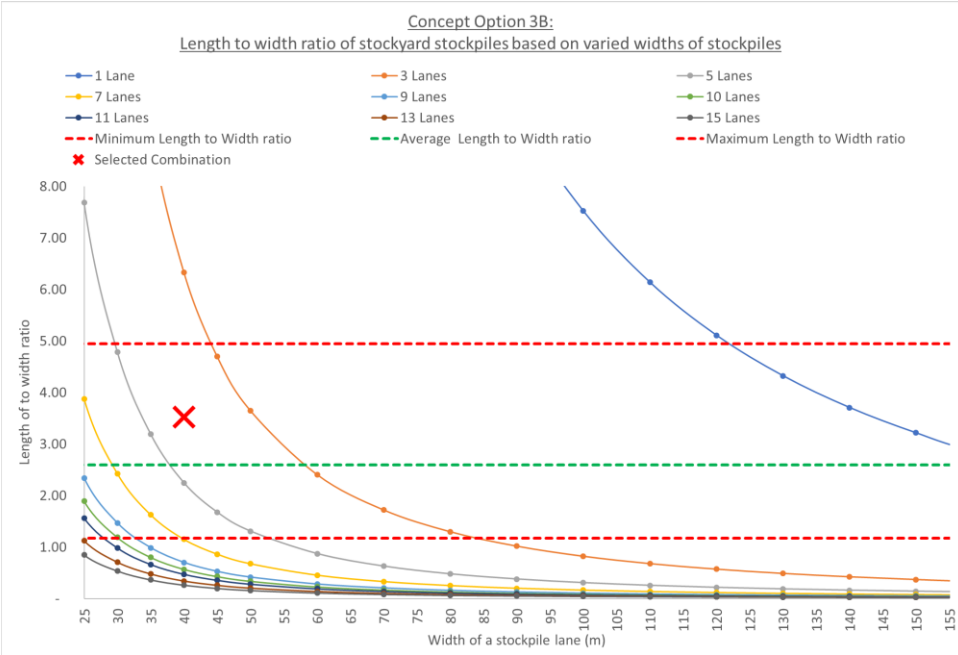
Concept Option 2A – Carrington Coal Terminal



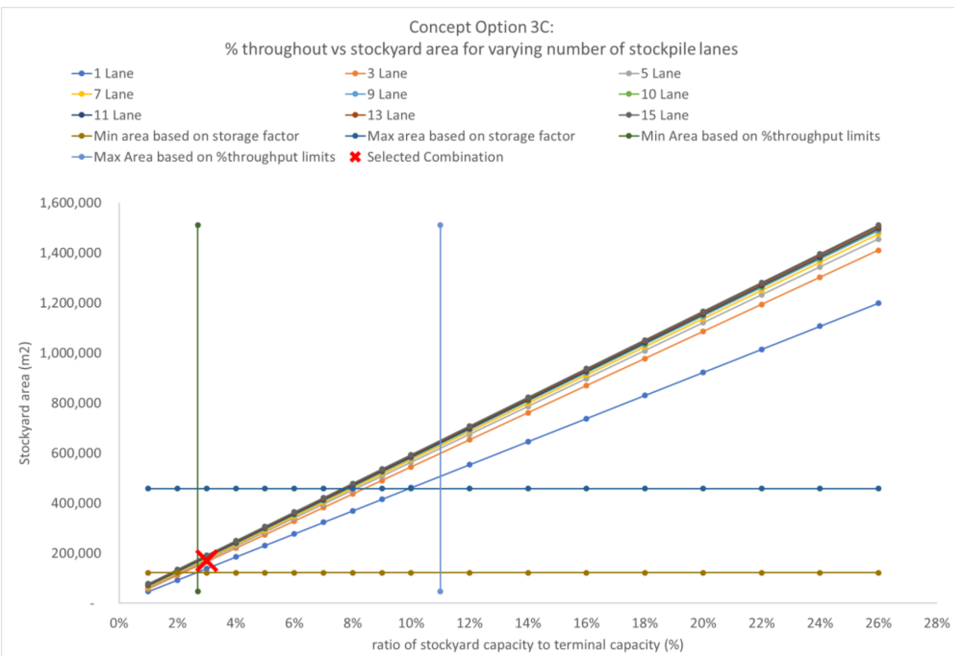
Concept Option 3A – Carrington Coal Terminal



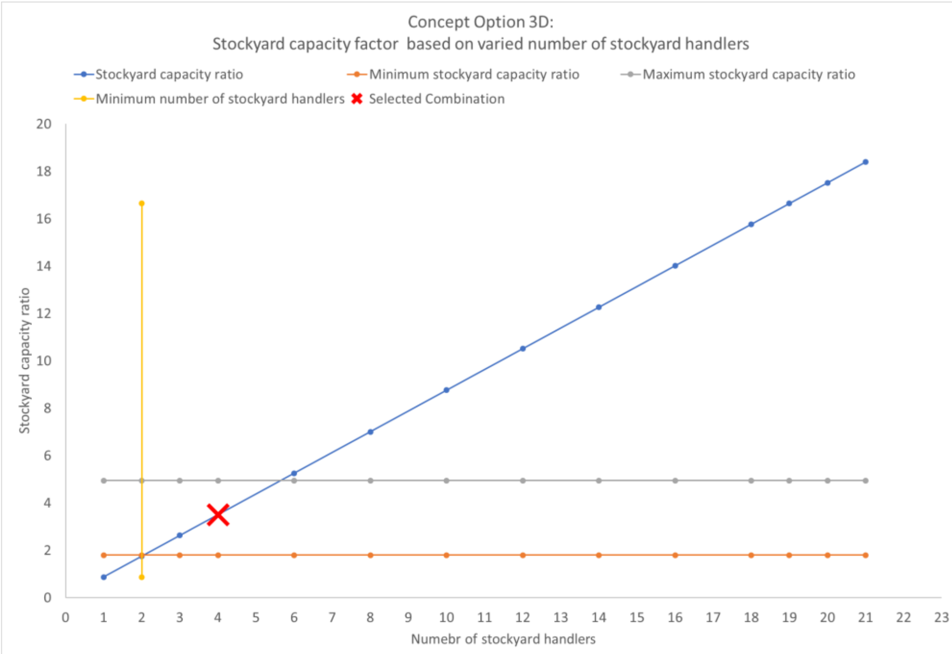
Concept Option 3B – Carrington Coal Terminal



Concept Option 3C – Carrington Coal Terminal

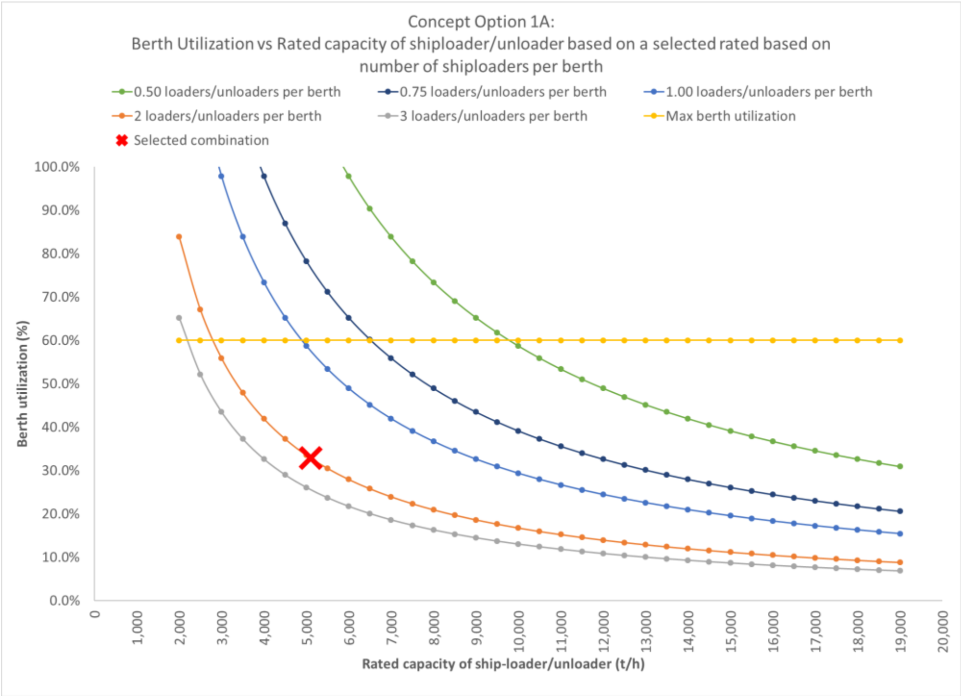


Concept Option 3D – Carrington Coal Terminal

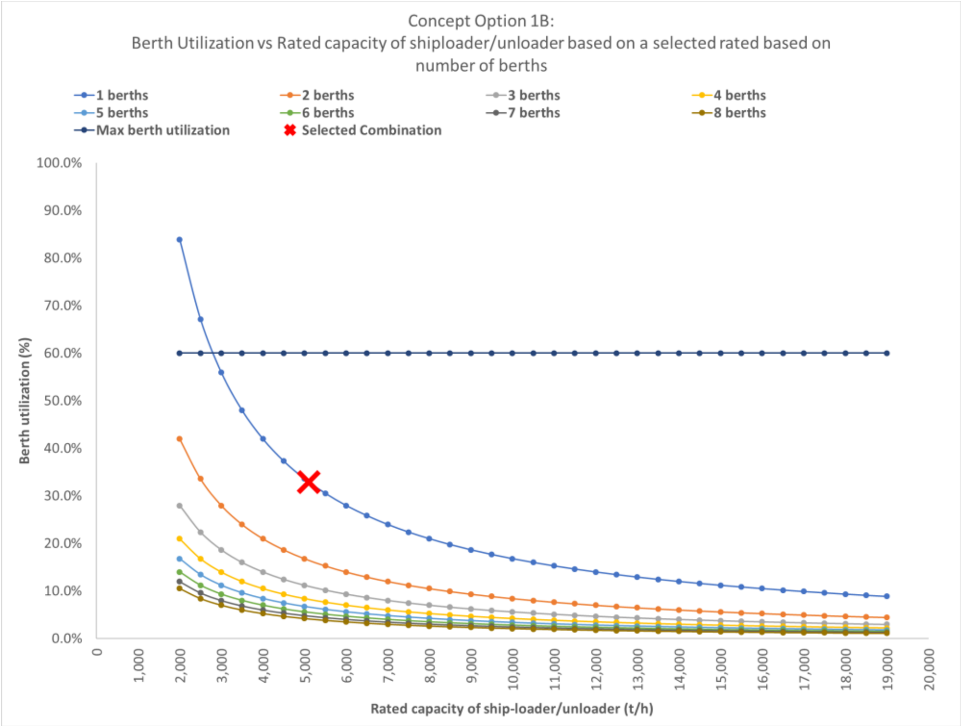


A.6 Nacala-a-Velha Coal Terminal, Port of Nacala, Mozambique

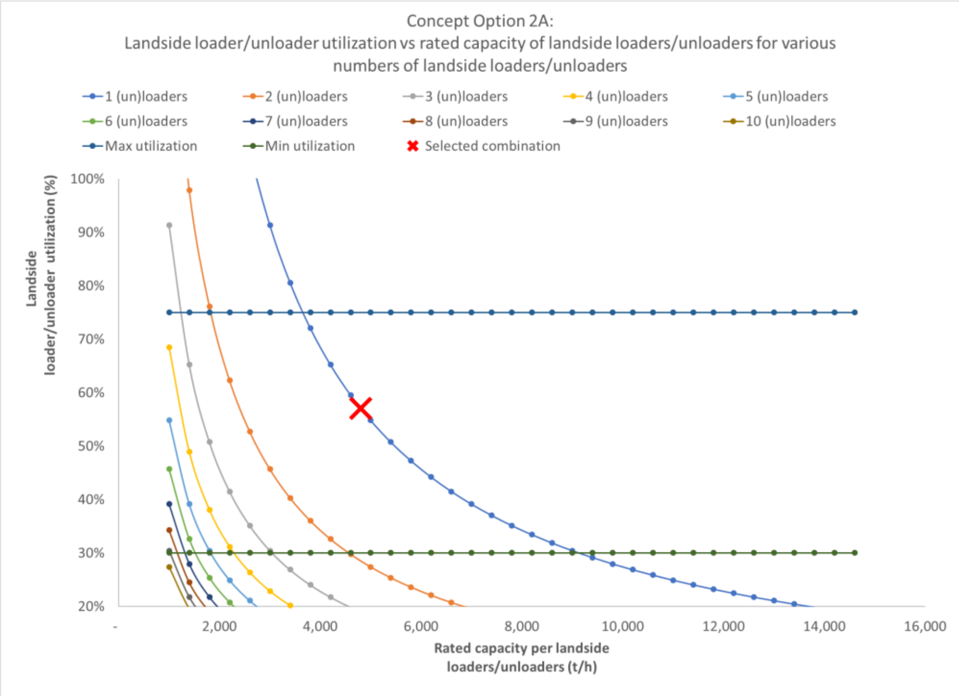
Concept Option 1A – Nacala-a-Velha



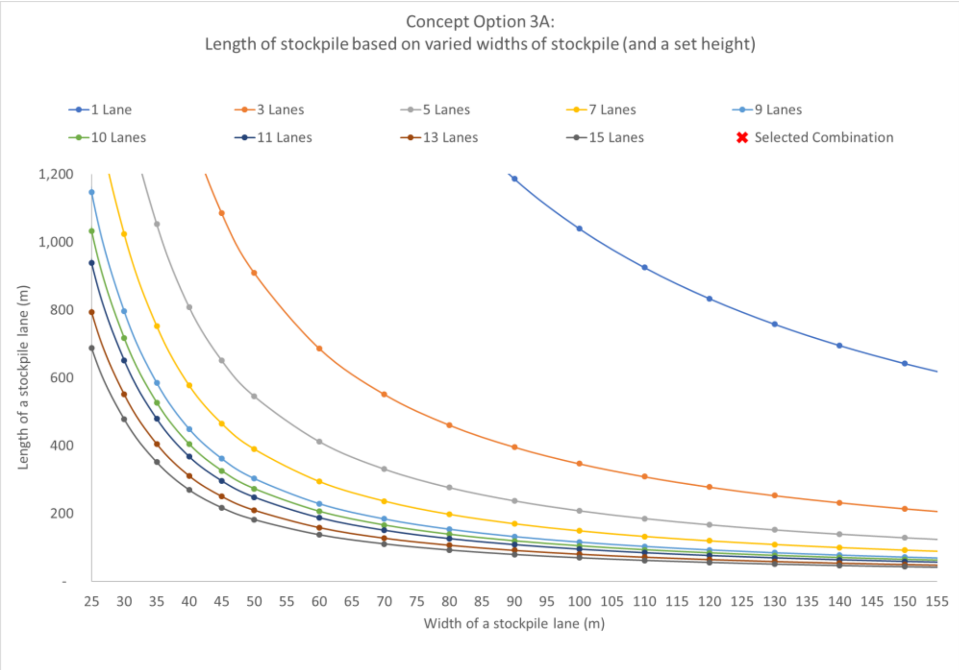
Concept Option 1B – Nacala-a-Velha



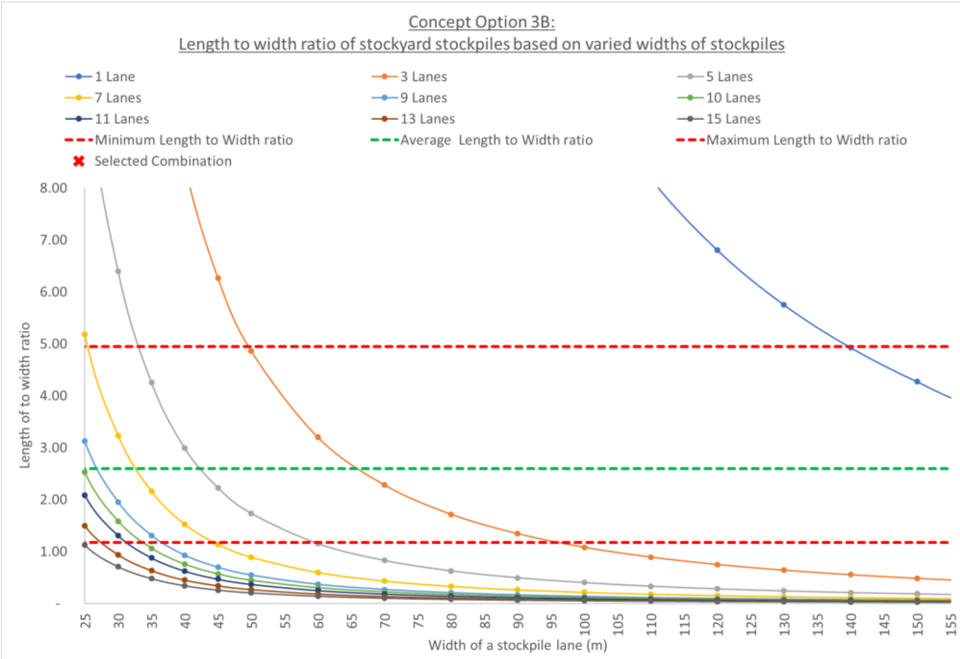
Concept Option 2A – Nacala-a-Velha



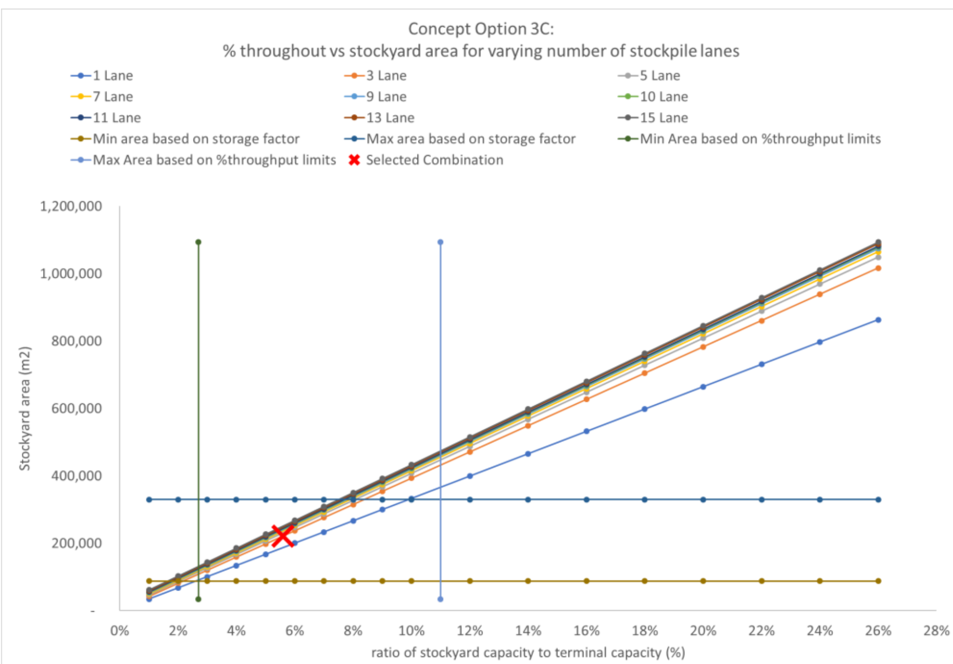
Concept Option 3A – Nacala-a-Velha



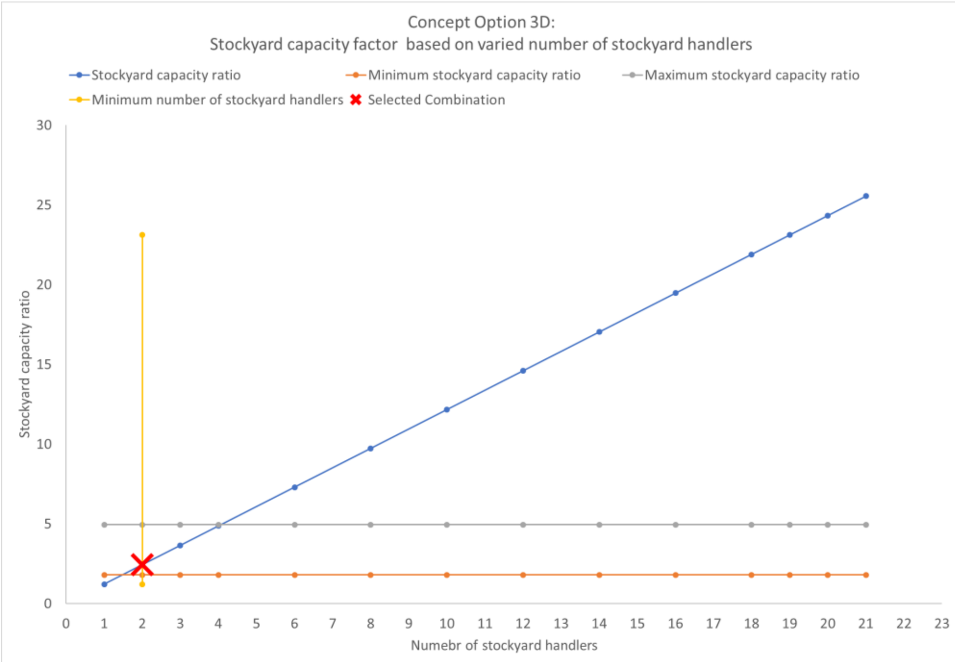
Concept Option 3B – Nacala-a-Velha



Concept Option 3C – Nacala-a-Velha



Concept Option 3D – Nacala-a-Velha



B. Appendix B: Characteristics of selected dry bulk terminals

Table B-1: Consolidated characteristics of researched dry bulk terminals

Terminal name	Kooragang coal terminal	Ponta da Madeira, Sao Luis	Richards Bay Coal Terminal	Port of Saldanha	EMO, Port of Rotterdam
Location	**Australia**	**Brazil**	**South Africa**	**South Africa**	**Netherlands**
Terminal type	Export	Export	Export	Export	Import
Primary commodity	Coal	Iron Ore	Coal	Iron Ore	Coal
Throughput capacity (MTPA)	120	190	91	60	60
Number of berths	5	5	6	2	4
Quay Length (metres)	1,396	1,915	2,200	630	1,365
Quay length factor	85.96	99.22	41.36	95.24	43.96
Number of loaders/unloaders per berth	0.60	1.60	0.67	1.00	1.00
Total number of loaders/unloaders	3	8	4	2	4
Total installed handling capacity of terminal	31,500	64,000	39,000	16,000	14,000
Rated / average capacity per loader/unloader	10,500	8,000	9,750	8,000	3500
Total number of landside loaders/unloaders (tandem tipplers count as two loaders/unloaders)	4	Not stated	10	2	6
Rated capacity per landside loader/unloader	8,500	Not stated	2,750	8,000	3,800
Total rated capacity of landside loaders/unloaders	34,000	Not stated	27,500	16,000	22,800
Storage capacity (million tonnes)	4.2	14.0	8.2	5.1	10.0
% of throughput required in storage	3.5%	7.4%	9.0%	8.5%	16.7%
Number of stockpile lanes	4	17	7	8	7
Width of stockpile lanes	56	40	70	50	65
Average length of stockpile lanes	2,500	1,180	1,900	640	1,400
Total width of stockyard	310	1,300	650	560	690

Terminal name	Kooragang coal terminal	Ponta da Madeira, Sao Luis	Richards Bay Coal Terminal	Port of Saldanha	EMO, Port of Rotterdam
Total area of stockyard	775,000	1,534,000	1,235,000	358,400	966,000
Number of stacker reclaimers	6	19	10	4	6
Total rated capacity of landside handlers	34,000	Not stated	27,500	16,000	22,800
Rated capacity per landside handlers	8,500	Not stated	2,750	8,000	3,800
Total rated capacity of seaside handlers (all berths and all handlers)	31,500	64,000	39,000	16,000	14,000
Total rated capacity of seaside handlers per berth	10,500	8,000	9,750	8,000	3,500
Stacking/reclaiming capacity per stockyard handler (average)	8,500	10,000	4,300	8,000	6,000
Total stacking/reclaiming capacity of all stockyard handlers	51,000	190,000	43,000	32,000	36,000

(Sources: Dry Cargo International, 2018; Pilbara Ports Authority, 2020; Port Waratah Coal Services, 2020; Richards Bay Coal Terminal, 2014; Transnet Port Terminals, 2013; Vale, 2015)

Table B-2: Consolidated characteristics of researched dry bulk terminals

Terminal name	Carrington coal terminal	Nacala-a-Velha	Hansapoort, Hamburg	Ridley coal terminal
Location	Australia	Mozambique	Germany	Canada
Terminal type	Export	Export	Import	Export
Primary commodity	Coal	Coal	Coal	Coal
Throughput capacity (MTPA)	25	18	18	16
Number of berths	2	1	4	2
Quay Length (metres)	615	385	760	320
Quay length factor	40.65	46.75	23.68	50.00
Number of loaders/unloaders per berth	1.00	2.00	1.00	1.00
Total number of loaders/unloaders	2	2	4	2
Total installed handling capacity of terminal	5,000	10,200	4,800	9,000
Rated / average capacity per loader/unloader	2500	5100	1200	4500
Total number of landside loaders/unloaders (tandem tipplers count as two loaders/unloaders)	2	1	1	1
Rated capacity per landside loader/unloader	4,500	4,800	6,500	6,500
Total rated capacity of landside loaders/unloaders	9,000	4,800	6,500	6,500
Storage capacity (million tonnes)	0.75	1.0	3.0	1.4
% of throughput required in storage	3.0%	5.6%	16.7%	8.8%
Number of stockpile lanes	4	3	8	4
Width of stockpile lanes	40	40	40	65
Average length of stockpile lanes	1,000	1,100	780	780
Total width of stockyard	230	200	350	360
Total area of stockyard	230,000	220,000	273,000	280,800
Number of stacker reclaimers	4	2	5	3
Total rated capacity of landside handlers	9,000	4,800	6,500	6,500
Rated capacity per landside handlers	4,500	4,800	6,500	6,500
Total rated capacity of seaside handlers (all berths and all handlers)	5,000	10,200	4,800	9,000
Total rated capacity of seaside handlers per berth	2,500	5,100	1,200	4,500

Terminal name	Carrington coal terminal	Nacala-a-Velha	Hansapoort, Hamburg	Ridley coal terminal
Stacking/reclaiming capacity per stockyard handler (average)	2,500	5,100	5,500	6,500
Total stacking/reclaiming capacity of all stockyard handlers	10,000	10,200	27,500	19,500

(Sources: Global Energy Monitor, 2019; Port of Hamburg, 2020; Port Waratah Coal Services, 2020; Ridley Terminals Inc, 2020; Synergia Consulting, 2016; Vale, 2015; Wilson Sons, 2020)